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# A Tentative Analysis of the Distribution Pattern of Tuna Projected on the Long-line Ⅱ※

Correlation of the hooked positions of the individuals of any two species of tuna among the yellow-fin tuna, the big-eye tuna and the albacore, and the analyses on the projected distribution pattern of the yellow-fin tuna through the interval analysis and the arrangement one

by

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## Introduction

The distribution patterns of the yellow-fin tuna (*Neothunnus albacora*), the big-eye tuna (*Parathunnus obesus*) and the albacore (*Thunnus alalunga*) projected along long-lines were minutely analyzed in the first report of this series of works (MAÉDA, 1960) by applying one of the analysis methods of sequence, most of which were newly constructed being based on the theory of probability for the purpose of fulfilling the peculiar conditions specific to long-line. But only short description and a few example of the correlation among the hooked-positions of individuals of the different species were illustrated; and also concerning the interval analysis and the arrangement one, nothing else than the short description of constructing-method of the formulae was described. Therefore, this report is written for the purpose of supplementing these deficiencies in the first report. And at first the relations of hooked-positions among the individuals of the same species will be shown as the preliminary step to the correlation analysis, next the correlations of hooked-positions observable among the individuals of two species (yellow-fin tuna——big-eye tuna, yellow-fin tuna——albacore and big-eye tuna——albacore) will be represented, which are one of the principal subjects of this report, then the results of the interval analysis and the arrangement one on the hooked-positions of the individuals of the yellow-fin tuna will be illustrated and compared with the results of the spacing analysis. And lastly some tracks of trials for exclusion of the influence of the presence of buoy-lines on the arrangement analysis will be added.

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## The Method for Collecting the Data
## (Fishing method)

The data used in the present study was offered by the Dai-fuji maru which obtained in the waters central part of the Indian Ocean during the period from April 5 to 16, 1955. A sketch chart of the fishing ground is shown in Fig. 1. The number

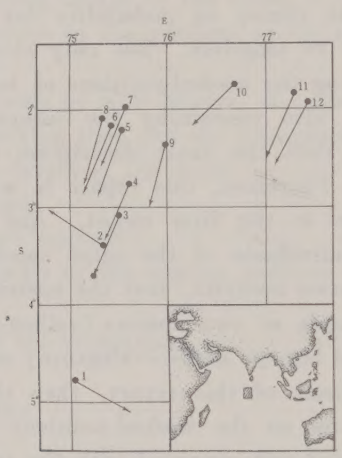



Fig. 1. Chart of the fishing ground.
Notes : Arrows show the length and the hauling direction of gears; solid circles indicate the initial points of hauling. And the numbers represent the station.

Table 1. The date, the number of used gears and the catch-composition at each station.

| St. | Date | No. of gear | Catch-composition | | | |
|---|---|---|---|---|---|---|
| | | | Yellow-fin tuna | Big-eye tuna | Albacore | Other fishes |
| 1 | Apr. 5,'55 | 372 | 180 | 13 | 2 | 49 |
| 2 | 6 | 372 | 229 | 9 | 14 | 56 |
| 3 | 7 | 374 | 214 | 17 | 41 | 59 |
| 4 | 8 | 375 | 153 | 14 | 24 | 31 |
| 5 | 9 | 370 | 158 | 21 | 70 | 33 |
| 6 | 10 | 375 | 254 | 44 | 45 | 27 |
| 7 | 11 | 377 | 224 | 27 | 37 | 26 |
| 8 | 12 | 167 | 49 | 6 | 13 | 9 |
| 9 | 13 | 231 | 70 | 7 | 3 | 18 |
| 10 | 14 | 376 | 135 | 47 | 18 | 38 |
| 11 | 15 | 373 | 230 | 14 | 8 | 30 |
| 12 | 16 | 373 | 160 | 16 | 13 | 32 |

Notes : Position at each station is shown in Fig. 1. Damaged individuals and juvenile ones are included.

of used gears and the composition of respective catches are given in Table 1. Each set of gears consists of *ca.* 380 main-lines (a main-line is usually represented in the word "a basket", because it is put in a basket when it is not in use) connected in a series and suspended in the water by buoy-lines of 20 m long each attached at every joint. Each main-line is 300 m long and provided with four branch-lines of 25 m long set at regular intervals and each ending in a single hook. The interval between each pair of hook on the same basket is 60 m, while the interval between the distal hook of a certain basket and the adjoining one of the consecutive basket is twice as long as this. As each main-line of respective unit of gears forms catenarian, the average buoy-interval is shorter than the length of the main-line in the actual operation and thus the hooks cannot be suspended at the same level, but their situations are separated into two levels. And the depth level of the adjoining hooks to buoy-lines (the first and the hindmost hooks in respective baskets) is measured by chemical tube to be about 100 m deep while that of the rests of them is to be about 150 m deep. Therefore, hereafter, the hooks belonging to the former group are, for convenience' sake, called the shallower hooks and the rests of them deeper ones. The gears are set from one end and it takes about four hours to empty all the baskets. The setting always begins at midnight, the boat is let drift for about three hours near the final end of the whole gear and then the hauling of gears begins with the final end of the whole gear. This time, it takes about twelve hours or longer to haul up the whole gear. Thus the soaking of the whole gear lasts generally for three hours from 3 *a.m.* to 6 *a.m.*

# Part I Correlation Analysis (Including the spacing analysis as the preliminary step)

## Method of Analysis

The most commercially important problem on the distribution of tuna is how to find out the waters where the gears should be set or better catch is expected, and most of the efforts of commercial fishery and of studies on the distribution of tuna are concentrated on this problem; while the distribution pattern treated in this report is never the pattern observable in such a wide range but that observable within a row. And it is a well known fact that the fishes are by no means evenly distributed throughout the bio-geographical zone but showing some sparse and dense. No one perceived clearly the strong school formation or observed schooling adult tuna in the ocean under usual condition, in considering by such a scale as treated in this report; but slight schooling (MURPHY & ELLIOT, 1954) or no evidence supporting school formation (NAKAMURA, 1949, *etc.*) is suggested. The well coincident results with them were obtained in the first report, moreover, Figs. 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22 and 24, which represent the catch in each lot of five consecutive baskets of respective examples used in this report, also suggest the presence of no clear school. Accordingly, the following are safely set to be on the basic assumptions of the formulae applied to this report, as in the first report: if the soaking time and depth level of the hooks are the same, the occupied-rates* of all hooks are the same, and whether respective hooks occupied or not are independently of one another.

In the first report of this series of works, schooling tendency of respective species of tuna in respective examples were analyzed, adopting five consecutive baskets, basket and hook-interval (the word "hook-interval" is employed to represent the mean interval between adjoining hooks within the same basket) as the unit-length of consideration. But there are many examples, in which the individuals are rather widely and less densely scattered, consequently even if the unit-length of the consideration is elongated into five consecutive baskets (= 1 km or thereabout), the structure of the highest order expected to be observable within a row can be not so clearly suggested from the analysis interfered by the short-periodic deviation which is considered to be due to the structure of the subordinate orders. Therefore, it is desirable to add another series of analysis in which the section longer than five consecutive baskets is adopted as the unit-length of consideration. On the other hand, the unit-lengths adopted in two series of the first report, five consecutive baskets and a basket, were too apart from each other, which makes it difficult to deduce the pattern connecting the results of these two series of analyses. Therefore, it is also desirable to add

* The word "occupied-rate" used in this report indicates the occupied probability of a hook by individual of a certain species.

another series, the unit-length of which is the intermediate length between a basket and five consecutive ones. Owing to the above-mentioned reasons, two other series of analyses are added to this report, the unit-lengths of which are ten consecutive baskets and two consecutive ones respectively.

Equal number of shallower hooks and deeper ones and a half number of buoy-lines are contained in respective unit-sections of all series of analyses, except for the last one the unit-length of which is hook-interval. Accordingly, there is no need to pay any attention to the peculiar conditions specific to the long-line gears. Moreover, even if we adopt the method proposed in this series of works, it is very difficult, although not impossible, to exclude the influences of the facts that each hook is unable to be occupied by more than one individual and that the number of hooks contained in each section is not so much, consequently maximum number of individuals capable of being hooked in it is limited. Thus, correlogram or analysis method of run seem to be applicable. But I prefer to adopt the methods described in the below, because the influence of the presumable gradient of the occupied-rate due to that of soaking time is excludable adopting these methods, although examining method, applicable to these analysis methods into the question whether the difference in the observed-values from the estimated ones is significant or not, has not yet deviced out. But, for the last series in which all of the peculiar conditions specific to long-line are influential, it is evident that the method adopted in this report has much advantage, because influences of all the peculiar conditions can easily be excluded.

Therefore, at first, the constructing-process of the formulae of spacing analysis applicable to the series, the unit-length under consideration of which is divisible by a basket length, will be shown. Next, those applicable to the analysis, in which the unit-length is as long as hook-interval, and lastly those of correlation analysis will be illustrated.

## 1. Spacing analysis 1. (Unit-length is divisible by a basket length)

Let us set that the number of the individuals caught in the *ith* section is $N_i = (N_0 + i\Delta N)$, total number of individuals caught by a row of gears constituted of $M$ consecutive sections is $N=\sum_{i=1}^{M}(N_0 +i\Delta N)$, and all individuals are distributed showing simple gradient due to that of soaking time. The probability of a certain individual caught in the *ith* section is represented as $P_i =\frac{N_i}{N}=\frac{N_0 +i\Delta N}{N}=P_0 +i\Delta P$. Then, the probability of any two individuals caught in the *ith* section is $(P_0 +i\Delta P)^2$. And the expectant number of the individual-pairs constituted of those hooked within the same unit when no interference among individuals is observable, $X_{(0)}$, is represented as follows, because "$i$" varies from 1 to $M$ and the number of combinations picking up any two individuals from $N$ hooked-individuals is $\frac{N(N-1)}{2}$:

$$X_{(0)}=\frac{N(N-1)}{2}\sum_{i=1}^{M}(P_0+i\Delta P)^2$$

$$=\frac{MN(N-1)}{2}P_0^2\left[1+(M+1)\delta+(M+1)(2M+1)\frac{\delta^2}{6}\right] \quad \cdots\cdots (1)$$

here $\delta=\frac{\Delta P}{P_0}$.

The probability of occurrence in a certain individual in the *ith* section or the $(i+k)th$ one is $(P_0+i\Delta P)+(P_0+\overline{i+k}\Delta P)$; therefore that of any two individuals caught in the *ith* section or the $(i+k)th$ one is $\{(P_0+i\Delta P)+(P_0+\overline{i+k}\Delta P)\}^2$. But here, the probabilities of both individuals caught together in the same sections should be included; they are respectively $(P_0+i\Delta P)^2$ and $(P_0+\overline{i+k}\Delta P)^2$. Thus, the probability of any two individuals caught separately in the *ith* section and the $(i+k)th$ one is

$$\{(P_0+i\Delta P)+(P_0+\overline{i+k}\Delta P)\}^2-(P_0+i\Delta P)^2-(P_0+\overline{i+k}\Delta P)^2$$
$$=2(P_0+i\Delta P)(P_0+\overline{i+k}\Delta P).$$

"$i$" varies from 1 to $(M-k)$. Accordingly, for the same reasons as previously mentiond in the construction of Formula (1), the formula representing the expectant number of the individual-pairs of $k$ section-intervals wide $(k\neq 0)$ constituted of the individuals of the same species when no interference is observable among the individuals, $X_{(k)}$, is given as follows:

$$X_{(k)}=\frac{N(N-1)}{2}\times 2\sum_{i=1}^{M-k}(P_0+i\Delta P)(P_0+\overline{i+k}\Delta P)$$

$$=(M-k)N(N-1)P_0^2\left[1+(M+1)\delta+(M-k+1)(2M+k+1)\frac{\delta^2}{6}\right] \cdots\cdots (2)$$

here $\delta=\frac{\Delta P}{P_0}$.

Note:

1) Test method, examining into the question whether or not the difference in the observed-value from the estimated one at respective $k$ is significant, has not yet deviced out.

2) The individuals caught within respective sections are methodologically regarded to be caught at the centers of respective sections, despite of the fact that the individuals caught at the parts near an end of respective sections are, actually, more apart from the individuals caught at the parts near the other end within the same section than those caught at the adjoining part in the adjoining section. Thus, the observed-values contain the error added newly by the summing of catch within respective sections.

3) The observed-values may more or less differ according to the situation of the starting point to count the unit of $\nu$ consecutive baskets, because there are $\nu$ ways to section a row of gears by $\nu$ consecutive baskets.

4) If we wish to obtain both the observed-values and the estimated ones free from the influence of these sources of errors, as well as the errors caused by the fact that each hook can not be occupied by more than one individual, we will notice it may seem better to adopt the following method: at first, both the observed-values and the estimated ones are estimated by using the next method, which is applicable to the analysis, the unit-length under consideration of which is as long as hook-interval, then corresponding values may be obtained with summing up every consecutive $\nu$ $(H+1)$ values ( $H$ is the number of hooks attached to each basket).

5) But, the method described here is adopted in the consideration upon the pattern observable in a wide range, because the magnitude of the error caused by the above-mentioned sources is, actually, not so large, against the difficulty in obtaining the observed-values at longer hook-intervals and presumable computation error being afraid to be introduced in them.

## 2. Spacing analysis 2. ( Unit-length is hook-interval and applicable to the gears attaching to four hooks a basket )

The formulae illustrated in the preceding paragraph are applicable to any long-line gears regardless of the number of hooks attaching to each unit; while those shown in the following paragraph vary according to the number of hooks attached to each basket. Here, only the formulae applicable to the gears with four hooks a basket are represented.

Let us set that $N_1$ and $N_2$ individuals are scattered, showing a simple gradient, along shallower and deeper hooks in a row of gears constituted of $m$ consecutive baskets of equal length attached to four hooks a basket, and no interference is expected among the individuals. $k$ is represented as $a(4+1)+R$, when it is separated into the part divisible by the length of a basket and the remainder. Then the hooks spaced by $k$ hook-intervals from respective hooks in the $ith$ basket are repre-

Table 2. Hooks spaced by $k$ hook-intervals from respective hooks in the $ith$ basket $(H=4)$.

| R | Order of hook in the $ith$ basket | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| 0 | 1 | 2 | 3 | 4 |
| 1 | 2 | 3 | 4 | B |
| 2 | 3 | 4 | B | **1** |
| 3 | 4 | B | **1** | **2** |
| 4 | B | **1** | **2** | **3** |

Notes : $B$ indicates buoy-line. Numerals in respective columns, except those printed by gothic, indicate the order of hook in the $(i+a)th$ basket, while those by gothic show that in the $(i+a+1)th$ one. $k$ is represented by $a(4+1)+R$, when it is separated into the part divisible by the basket length and remainder.

sented as shown in Table 2. And the occupied-rates of a shallower and a deeper hook in the *ith* basket are expressed respectively $(P_1+i\Delta P_1)$ and $(P_2+i\Delta P_2)$ for the purpose of representing the simple gradient of occupied-rates. Then the occupied probabilities of the hooks corresponding to respective columns in Table 2 are illustrated in Table 3. Accordingly, the probabilities of occurrence in both of the two

Table 3. Occupied-rates corresponding to respective columns of Table 2; the influence of the gradient of the occupied-rate and that of the difference in the occupied-rate due to the difference in the fishing depths of the hooks are taken into consideration.

| R \ h | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| | $P_1+i\Delta P_1$ | $P_2+i\Delta P_2$ | $P_2+i\Delta P_2$ | $P_1+i\Delta P_1$ |
| 0 | $P_1+\overline{i+a}\Delta P_1$ | $P_2+\overline{i+a}\Delta P_2$ | $P_2+i+a\Delta P_2$ | $P_1+i+\overline{a}\Delta P_1$ |
| 1 | $P_2+i+a\Delta P_2$ | $P_2+\overline{i+a}\Delta P_2$ | $P_1+i+a\Delta P_1$ | 0 |
| 2 | $P_2+\overline{i+a}\Delta P_2$ | $P_1+\overline{i+a}\Delta P_1$ | 0 | $P_1+\overline{i+a+1}\Delta P_1$ |
| 3 | $P_1+\overline{i+a}\Delta P_1$ | 0 | $P_1+\overline{i+a+1}\Delta P_1$ | $P_2+\overline{i+a+1}\Delta P_2$ |
| 4 | 0 | $P_1+\overline{i+a+1}\Delta P_1$ | $P_2+\overline{i+a+1}\Delta P_2$ | $P_2+i+\overline{a+1}\Delta P_2$ |

hooks occupied and one of which is located in the *ith* basket while the other is spaced by $k$ hook-intervals from it are shown in Table 4. But, for the columns in

Table 4. Probability of occurrence in two occupied hooks spaced by $k$ hook-intervals each other.

| R \ Order of hook in the *ith* basket starting to count $k$ | 1 | | 2 | |
|---|---|---|---|---|
| 0 | $(P_1+i\Delta P_1)$ | $(P_1+\overline{i+a}\Delta P_1)$ | $(P_2+i\Delta P_2)$ | $(P_2+\overline{i+a}\Delta P_2)$ |
| 1 | $(P_1+i\Delta P_1)$ | $(P_2+\overline{i+a}\Delta P_2)$ | $(P_2+i\Delta P_2)$ | $(P_2+\overline{i+a}\Delta P_2)$ |
| 2 | $(P_1+i\Delta P_1)$ | $(P_2+i+a\Delta P_2)$ | $(P_2+i\Delta P_2)$ | $(P_1+\overline{i+a}\Delta P_1)$ |
| 3 | $(P_1+i\Delta P_1)$ | $(P_1+\overline{i+a}\Delta P_1)$ | | 0 |
| 4 | 0 | | $(\mathbf{P_2+i\Delta P_2})$ | $(\mathbf{P_1+\overline{i+a+1}\Delta P_1})$ |

| R \ Order of hook in the *ith* basket starting to count $k$ | 3 | | 4 | |
|---|---|---|---|---|
| 0 | $(P_2+i\Delta P_2)$ | $(P_2+\overline{i+a}\Delta P_2)$ | $(P_1+i\Delta P_1)$ | $(P_1+\overline{i+a}\Delta P_1)$ |
| 1 | $(P_2+i\Delta P_2)$ | $(P_1+\overline{i+a}\Delta P_1)$ | | 0 |
| 2 | | 0 | $(\mathbf{P_1+i\Delta P_1})$ | $(\mathbf{P_1+\overline{i+a+1}\Delta P_1})$ |
| 3 | $(\mathbf{P_2+i\Delta P_2})$ | $(\mathbf{P_1+\overline{i+a+1}\Delta P_1})$ | $(\mathbf{P_1+i\Delta P_1})$ | $(\mathbf{P_2+\overline{i+a+1}\Delta P_2})$ |
| 4 | $(\mathbf{P_2+i\Delta P_2})$ | $(\mathbf{P_2+\overline{i+a+1}\Delta P_2})$ | $(\mathbf{P_1+i\Delta P_1})$ | $(\mathbf{P_2+\overline{i+a+1}\Delta P_2})$ |

Notes are the same as in Table 2.

each of which one hook is picked up from the *ith* basket, and the other hook is from the $(i+a)th$ basket, "$i$" can vary from 1 to $(m-a)$; while for those in each of which one is picked up from the *ith* basket, and the other is from the $(i+a+1)th$ one, "$i$" varies from 1 to $(m-a-1)$. Accordingly, the expectant number of the

individual-pairs of $k$ hook-intervals wide and constituted of the same species is estimative from the following formulae:

at $R=0$

$$X_{(k)}=2\sum_{i=1}^{m-a}(P_1+i\Delta P_1)(P_1+\overline{i+a}\Delta P_1)+2\sum_{i=1}^{m-a}(P_2+i\Delta P_2)(P_2+\overline{i+a}\Delta P_2)$$

$$=2\left[P_1^2(m-a)\left\{1+(m+1)\delta_1+(m-a+1)(2m+a+1)\frac{\delta_1^2}{6}\right\}\right.$$

$$\left.+P_2^2(m-a)\left\{1+(m+1)\delta_2+(m-a+1)(2m+a+1)\frac{\delta_2^2}{6}\right\}\right] \quad \cdots\cdots(3)$$

$R=1$

$$X_{(k)}=\sum_{i=1}^{m-a}(P_1+i\Delta P_1)(P_2+\overline{i+a}\Delta P_2)+\sum_{i=1}^{m-a}(P_2+i\Delta P_2)(P_2+\overline{i+a}\Delta P_2)$$

$$+\sum_{i=1}^{m-a}(P_2+i\Delta P_2)(P_1+\overline{i+a}\Delta P_1)$$

$$=P_1P_2(m-a)\left[2+(m+1)(\delta_1+\delta_2)+(m-a+1)(2m+a+1)\frac{\delta_1\delta_2}{3}\right]$$

$$+P_2^2(m-a)\left[1+(m+1)\delta_2+(m-a+1)(2m+a+1)\frac{\delta_2^2}{6}\right] \quad \cdots\cdots(4)$$

$R=2$

$$X_{(k)}=\sum_{i=1}^{m-a}(P_1+i\Delta P_1)(P_2+\overline{i+a}\Delta P_2)+\sum_{i-1}^{m-a}(P_2+i\Delta P_2)(P_1+\overline{i+a}\Delta P_1)$$

$$+\sum_{i=1}^{m-a-1}(P_1+i\Delta P_1)(P_1+\overline{i+a+1}\Delta P_1)$$

$$=P_1P_2(m-a)\left[2+(m+1)(\delta_1+\delta_2)+(m-a+1)(2m+a+1)\frac{\delta_1\delta_2}{3}\right]$$

$$+P_1^2(m-a-1)\left[1+(m+1)\delta_1+(m-a)(2m+a+2)\frac{\delta_1^2}{6}\right] \quad \cdots\cdots(5)$$

$R=3$

$$X_{(k)}=\sum_{i=1}^{m-a}(P_1+i\Delta P_1)(P_1+\overline{i+a}\Delta P_1)+\sum_{i=1}^{m-a-1}(P_2+i\Delta P_2)(P_1+\overline{i+a+1}\Delta P_1)$$

$$+\sum_{i=1}^{m-a-1}(P_1+i\Delta P_1)(P_2+\overline{i+a+1}\Delta P_2)$$

$$=P_1^2(m-a)\left[1+(m+1)\delta_1+(m-a+1)(2m+a+1)\frac{\delta_1^2}{6}\right]$$

$$+P_1P_2(m-a-1)\left[2+(m+1)(\delta_1+\delta_2)+(m-a)(2m+a+2)\frac{\delta_1\delta_2}{3}\right] \quad \cdots\cdots(6)$$

and at R=4

$$X_{(k)}=\sum_{i=1}^{m-a-1}(P_2+i\Delta P_2)(P_1+i+\overline{a+1}\Delta P_1)+\sum_{i=1}^{m-a-1}(P_2+i\Delta P_2)(P_2+\overline{i+a+1}\Delta P_2)$$
$$+\sum_{i=1}^{m-a-1}(P_1+i\Delta P_1)(P_2+\overline{i+a+1}\Delta P_2)$$
$$=P_1P_2(m-a-1)\left[2+(m+1)(\delta_1+\delta_2)+(m-a)(2m+a+2)\frac{\delta_1\delta_2}{3}\right]$$
$$+P_2{}^2(m-a-1)\left[1+(m+1)\delta_2+(m-a)(2m+a+2)\frac{\delta_2{}^2}{6}\right] \quad \cdots\cdots (7)$$

here $\delta_1=\frac{\Delta P_1}{P_1}$ and $\delta_2=\frac{\Delta P_2}{P_2}$.

## 3. Correlation analysis 1. (Unit-length is divisible by a basket length)

Let us set that $N_A$ individuals of species $A$ and $N_B$ of species $B$ are distributed, showing simple gradient along a row of gears constituted of $M$ consecutive sections and no interference is observable among the individuals of both species. And in order to express the gradient of distribution, the number of individuals caught in the *ith* section is set as $(A_0+i\Delta A)$ for species $A$ and $(B_0+i\Delta B)$ for species $B$.

Here $N_A=\sum_{i=1}^{M}(A_0+i\Delta A)$ and $N_B=\sum_{i=1}^{M}(B_0+i\Delta B)$.

Number of the combinations to take one individual from species $A$ and the other from species $B$ observable in the *ith* section is $(A_0+i\Delta A)(B_0+i\Delta B)$. And "$i$" can vary from 1 to $M$. Accordingly the number of such combinations, individual-pairs constituted of the individuals of the different species while caught within the same section, $C_{(0)}$, observable in a whole row of gears is represented as follows:

$$C_{(0)}=\sum_{i=1}^{M}(A_0+i\Delta A)(B_0+i\Delta B)$$
$$=A_0B_0M\left[1+(M+1)\frac{\delta_A+\delta_B}{2}+(M+1)(2M+1)\frac{\delta_A\delta_B}{6}\right] \quad \cdots\cdots (8)$$

here $\delta_A=\frac{\Delta A}{A_0}$ and $\delta_B=\frac{\Delta B}{B_0}$.

But the number of the combinations to take one individual from species $A$ hooked in the *ith* section and the other from species $B$ hooked in the $(i+k)th$ section is $(A_0+i\Delta A)(B_0+i+k\Delta B)$. And *vice versa* is $(B_0+i\Delta B)(A_0+\overline{i+k}\Delta A)$. Accordingly the expectant number of the individual-pairs of $k$ section-intervals wide and constituted of the individuals belonging to the different species hooked one in the *ith* section while the other in the $(i+k)th$ one is the sum of them. And the number of

them observable in a whole row of gears is represented as follows, because "$i$" varies from 1 to $(M-k)$.

$$C_{(k)}=\sum_{i=1}^{M-k}\left\{(A_0+i\Delta A)(B_0+\overline{i+k}\Delta B)+(B_0+i\Delta B)(A_0+\overline{i+k}\Delta A)\right\}$$

$$=A_0B_0(M-k)\left[2+(M+1)(\delta_A+\delta_B)+(M-k+1)(2M+k+1)\frac{\delta_A\delta_B}{3}\right]\cdots\cdots\cdots(9)$$

here $\delta_A=\frac{\Delta A}{A_0}$ and $\delta_B=\frac{\Delta B}{B_0}$.

## 4. Correlation analysis 2. (Unit-length is hook-interval and applicable to the gears attaching to four hooks a basket)

Like the same as the spacing analysis, the formulae applicable to the analysis, unit-length of which is hook-interval, also take the different forms according to the number of hooks attaching to each basket. And, the formulae only applicable to the the gears attaching to four hooks a basket will be shown.

For the purpose of representing the simple gradient of distribution due to that of the soaking time and the difference in the occupied-rates due to that of settled depth levels of hooks, let us set that the occupied-rates of respective hooks by respective species take the values represented in Table 5 (c). When $k$ is represented as

Table 5. Probability of occurrence in two hooks, one of which is located in the $ith$ basket and occupied by the individual of species $A$ while the other is spaced by $k$ hook-intervals from it and occupied by the individual of species $B$ ( a ), and that in which the occupying species are mutually replaced ( b ).

( a )

| R | Order of hook in the $ith$ basket starting to count $k$ | | | |
|---|---|---|---|---|
| | 1 | | 2 | |
| 0 | (Aso+iΔAs) | (Bso+i+aΔBs) | (Ado+iΔAd) | (Bdo+i+aΔBd) |
| 1 | (Aso+iΔAs) | (Bdo+$\overline{i+a}$ΔBd) | (Ado+iΔAd) | (Bdo+$\overline{i+a}$ΔBd) |
| 2 | (Aso+iΔAs) | (Bdo+$\overline{i+a}$ΔBd) | (Ado+iΔAd) | (Bso+$\overline{i+a}$ΔBs) |
| 3 | (Aso+iΔAs) | (Bso+$\overline{i+a}$ΔBs) | | 0 |
| 4 | | 0 | (Ado+iΔAd) | (Bso+$\overline{i+a+1}$ΔBs) |

| R | Order of hook in the $ith$ basket starting to count $k$ | | | |
|---|---|---|---|---|
| | 3 | | 4 | |
| 0 | (Ado+iΔAd) | (Bdo+$\overline{i+a}$ΔBd) | (Aso+iΔAs) | (Bso+$\overline{i+a}$ΔBs) |
| 1 | (Ado+iΔAd) | (Bso+i+aΔBs) | | 0 |
| 2 | | 0 | (Aso+iΔAs) | (Bso+i+a+1ΔBs) |
| 3 | (Ado+iΔAd) | (Bso+$\overline{i+a+1}$ΔBs) | (Aso+iΔAs) | (Bdo+$\overline{i+a+1}$ΔBd) |
| 4 | (Ado+iΔAd) | (Bdo+$\overline{i+a+1}$ΔBd) | (Aso+iΔAs) | (Bdo+i+a+1ΔBd) |

( b )

| R | Order of hook in the *ith* basket starting to count *k* | | | |
|---|---|---|---|---|
| | 1 | | 2 | |
| 0 | (Bso+iΔBs) | (Aso+$\overline{i+a}$ΔAs) | (Bdo+iΔBd) | (Ado+i+aΔAd) |
| 1 | (Bso+iΔBs) | (Ado+$\overline{i+a}$ΔAd) | (Bdo+iΔBd) | (Ado+i+aΔAd) |
| 2 | (Bso+iΔBs) | (Ado+$\overline{i+a}$ΔAd) | (Bdo+iΔBd) | (Aso+i+aΔAs) |
| 3 | (Bso+iΔBs) | (Aso+i+aΔAs) | | 0 |
| 4 | | 0 | (Bdo+iΔBd) | (Aso+i+a+1ΔAs) |

| R | Order of hook in the *ith* basket starting to count *k* | | | |
|---|---|---|---|---|
| | 3 | | 4 | |
| 0 | (Bdo+iΔBd) | (Ado+$\overline{i+a}$ΔAd) | (Bso+iΔBs) | (Aso+$\overline{i+a}$ΔAs) |
| 1 | (Bdo+iΔBd) | (Aso+$\overline{i+a}$ΔAs) | | 0 |
| 2 | | 0 | (Bso+iΔBs) | (Aso+$\overline{i+a+1}$ΔAs) |
| 3 | (Bdo+iΔBd) | (Aso+$\overline{i+a+1}$ΔAs) | (Bso+iΔBs) | (Ado+$\overline{i+a+1}$ΔAd) |
| 4 | (Bdo+iΔBd) | (Ado+$\overline{i+a+1}$ΔAd) | (Bso+iΔBs) | (Ado+$\overline{i+a+1}$ΔAd) |

Note: Probability of occurrence in the individual of respective species to respective hooks are represented as follows:

( c )

| | Order of basket | | | | | |
|---|---|---|---|---|---|---|
| | i | | i+a | | i+a+1 | |
| | Shallower | Deeper | Shallower | Deeper | Shallower | Deeper |
| A | (Aso+iΔAs) | (Ado+iΔAd) | (Aso+i+aΔAs) | (Ado+i+aΔAd) | (Aso+i+a+1ΔAs) | (Ado+i+a+1ΔAd) |
| B | (Bso+iΔBs) | (Bdo+iΔBd) | (Bso+$\overline{i+a}$ΔBs) | (Bdo+$\overline{i+a}$ΔBd) | (Bso+$\overline{i+a+1}$ΔBs) | (Bdo+$\overline{i+a+1}$ΔBd) |

$a(4+1)+R$ by the same way as that shown in the spacing analysis, the hooks spaced by $k$ hook-intervals from respective hooks in the *ith* basket are shown in Table 2. Accordingly, when no interference is observable among the individuals of both species, number of the combinations picking up one individual from species $A$ hooked in the *ith* basket and the other from species $B$ spaced by $k$ hook-intervals from it is horizontal sum of columns in Table 5 (a); while *vice versa* is that in Table 5 (b). Here, for the columns in which one hook is picked up from the *ith* basket while the other is in the $(i+a)th$ one, "$i$" can vary from 1 to $(m-a)$. But about the rests of them, "$i$" varies from 1 to $(m-a-1)$. Therefore, the expectant number of the individual-pairs of $k$ hook-intervals wide and constituted of the different species can be represented as follows:

at $R=0$

$$C_{(k)}=2\sum_{i=1}^{m-a}(As_0+i\Delta As)(Bs_0+\overline{i+a}\Delta Bs)+2\sum_{i=1}^{m-a}(Ad_0+i\Delta Ad)(Bd_0+\overline{i+a}\Delta Bd)$$

$$+2\sum_{i=1}^{m-a}(Bs_0+i\Delta Bs)(As_0+\overline{i+a}\Delta As)+2\sum_{i=1}^{m-a}(Bd_0+i\Delta Bd)(Ad_0+\overline{i+a}\Delta Ad)$$

$$=2As_0\,Bs_0(m-a)\left[2+(m+1)(\delta A_s+\delta B_s)+(m-a+1)(2m+a+1)\frac{\delta A_s\,\delta B_s}{3}\right]$$

$$+2Ad_0\,Bd_0(m-a)\left[2+(m+1)(\delta A_d+\delta B_d)+(m-a+1)(2m+a+1)\frac{\delta A_d\,\delta B_d}{3}\right]\cdots(10)$$

R=1

$$C_{(k)}=\sum_{i=1}^{m-a}(As_0+i\Delta As)(Bd_0+\overline{i+a}\Delta Bd)+\sum_{i=1}^{m-a}(Bs_0+i\Delta Bs)(Ad_0+\overline{i+a}\Delta Ad)$$

$$+\sum_{i=1}^{m-a}(Ad_0+i\Delta Ad)(Bd_0+\overline{i+a}\Delta Bd)+\sum_{i=1}^{m-a}(Bd_0+i\Delta Bd)(Ad_0+\overline{i+a}\Delta Ad)$$

$$+\sum_{i=1}^{m-a}(Ad_0+i\Delta Ad)(Bs_0+\overline{i+a}\Delta Bs)+\sum_{i=1}^{m-a}(Bd_0+i\Delta Bd)(As_0+\overline{i+a}\Delta As)$$

$$=As_0\,Bd_0(m-a)\left[2+(m+1)(\delta A_s+\delta B_d)+(m-a+1)(2m+a+1)\frac{\delta A_s\,\delta B_d}{3}\right]$$

$$+Ad_0\,Bs_0(m-a)\left[2+(m+1)(\delta A_d+\delta B_s)+(m-a+1)(2m+a+1)\frac{\delta A_d\,\delta B_s}{3}\right]$$

$$+Ad_0\,Bd_0(m-a)\left[2+(m+1)(\delta A_d+\delta B_d)+(m-a+1)(2m+a+1)\frac{\delta A_d\,\delta B_d}{3}\right]\cdots(11)$$

R=2

$$C_{(k)}=\sum_{i=1}^{m-a}(As_0+i\Delta As)(Bd_0+\overline{i+a}\Delta Bd)+\sum_{i=1}^{m-a}(Bs_0+i\Delta Bs)(Ad_0+\overline{i+a}\Delta Ad)$$

$$+\sum_{i=1}^{m-a}(Ad_0+i\Delta Ad)(Bs_0+\overline{i+a}\Delta Bs)+\sum_{i=1}^{m-a}(Bd_0+i\Delta Bd)(As_0+\overline{i+a}\Delta As)$$

$$+\sum_{i=1}^{m-a-1}(As_0+i\Delta As)(Bs_0+\overline{i+a+1}\Delta Bs)$$

$$+\sum_{i=1}^{m-a-1}(Bs_0+i\Delta Bs)(As_0+\overline{i+a+1}\Delta As)$$

$$=As_0\,Bd_0(m-a)\left[2+(m+1)(\delta A_s+\delta B_d)+(m-a+1)(2m+a+1)\frac{\delta A_s\,\delta B_d}{3}\right]$$

$$+Ad_0\,Bs_0(m-a)\left[2+(m+1)(\delta A_d+\delta B_s)+(m-a+1)(2m+a+1)\frac{\delta A_d\,\delta B_s}{3}\right]$$

$$+As_0\,Bs_0(m-a-1)\left[2+(m+1)(\delta A_s+\delta B_s)+(m-a)(2m+a+2)\frac{\delta A_s\,\delta B_s}{3}\right]\cdots(12)$$

R=3

$$C_{(k)}=\sum_{i=1}^{m-a}(As_0+i\Delta As)(Bs_0+\overline{i+a}\Delta Bs)+\sum_{i=1}^{m-a}(Bs_0+i\Delta Bs)(As_0+\overline{i+a}\Delta As)$$
$$+\sum_{i=1}^{m-a-1}(Ad_0+i\Delta Ad)(Bs_0+\overline{i+a+1}\Delta Bs)$$
$$+\sum_{i=1}^{m-a-1}(Bd_0+i\Delta Bd)(As_0+\overline{i+a+1}\Delta As)$$
$$+\sum_{i=1}^{m-a-1}(As_0+i\Delta As)(Bd_0+\overline{i+a+1}\Delta Bd)$$
$$+\sum_{i=1}^{m-a-1}(Bs_0+i\Delta Bs)(Ad_0+\overline{i+a+1}\Delta Ad)$$
$$=As_0\,Bs_0\,(m-a)\left[2+(m+1)(\delta A_s+\delta B_s)+(m-a+1)(2m+a+1)\frac{\delta A_s\,\delta B_s}{3}\right]$$
$$+Ad_0\,Bs_0\,(m-a-1)\left[2+(m+1)(\delta A_d+\delta B_s)+(m-a)(2m+a+2)\frac{\delta A_d\,\delta B_s}{3}\right]$$
$$+As_0\,Bd_0\,(m-a-1)\left[2+(m+1)(\delta A_s+\delta B_d)+(m-a)(2m+a+2)\frac{\delta A_s\,\delta B_d}{3}\right]\cdots(13)$$

R=4

$$C_{(k)}=\sum_{i=1}^{m-a-1}(Ad_0+i\Delta Ad)(Bs_0+i+a+1\Delta Bs)$$
$$+\sum_{i=1}^{m-a-1}(Bd_0+i\Delta Bd)(As_0+\overline{i+a+1}\Delta As)$$
$$+\sum_{i=1}^{m-a-1}(Ad_0+i\Delta Ad)(Bd_0+\overline{i+a+1}\Delta Bd)$$
$$+\sum_{i=1}^{m-a-1}(Bd_0+i\Delta Bd)(Ad_0+i+a+1\Delta Ad)$$
$$+\sum_{i=1}^{m-a-1}(As_0+i\Delta As)(Bd_0+i+a+1\Delta Bd)$$
$$+\sum_{i=1}^{m-a-1}(Bs_0+i\Delta Bs)(Ad_0+i+a+1\Delta Ad)$$
$$=Ad_0\,Bs_0\,(m-a-1)\left[2+(m+1)(\delta A_d+\delta B_s)+(m-a)(2m+a+2)\frac{\delta A_d\,\delta B_s}{3}\right]$$
$$+As_0\,Bd_0\,(m-a-1)\left[2+(m+1)(\delta A_s+\delta B_d)+(m-a)(2m+a+2)\frac{\delta A_s\,\delta B_d}{3}\right]$$

$$+\mathrm{Ad}_0\,\mathrm{Bd}_0\,(m-a-1)\left[2+(m+1)(\delta\mathrm{A_d}+\delta\mathrm{B_d})+(m-a)(2m+a+2)\frac{\delta\mathrm{A_d}\,\delta\mathrm{B_d}}{3}\right]\cdots(14)$$

Here $\delta\mathrm{A_s}=\dfrac{\Delta\mathrm{As}}{\mathrm{As}_0}$, $\delta\mathrm{A_d}=\dfrac{\Delta\mathrm{Ad}}{\mathrm{Ad}_0}$, $\delta\mathrm{B_s}=\dfrac{\Delta\mathrm{Bs}}{\mathrm{Bs}_0}$ and $\delta\mathrm{B_d}=\dfrac{\Delta\mathrm{Bd}}{\mathrm{Bd}_0}$.

## 5. Estimation of constants of the formulae used in this report

The constants used in the first report of this series of works were estimated from the regression lines of the catch in respective lots of 50 consecutive baskets wide on lot number; while for the purpose of computing the constants introducing lesser computation error into the estimated-values in these analyses, at first, as mentioned in the chapter "consideration upon the error" in the first report, only $\Delta P$ or $\Delta P_1$ and $\Delta P_2$ are computed from the regression lines of the catch in respective lots on lot number, in which each lot is shortened into a width of 20 consecutive baskets for the purpose of not only increasing the number of lots but also lessening the hindmost residual part which can not reach a lot and is neglected from the estimation of regression line, because the largest error is introduced by neglect of it; next $P_0$ or $P_1$ and $P_2$ are computed from the equation $N=\sum_{i=1}^{M}(P_0+i\Delta P)$ or $N_1=2\sum_{i=1}^{M}(P_1+i\Delta P_1)$ and $N_2=2\sum_{i=1}^{M}(P_2+i\Delta P_2)$, because the next large error is caused by the fact that $N\neq\sum_{i=1}^{M}(P_0+i\Delta P)$, here $M=\dfrac{m}{20}$. And lastly, $P$ and $\Delta P$ *etc.* per lot of 20 consecutive baskets are converted into corresponding values per respective unit-lengths under consideration. And a series of the estimated constants per basket is shown in Table 6 as an example and the methods for conversion are added to this table.

Table 6. Estimated constants of respective species in respective examples.

| Species | Example No. | m | $N_1$ | $N_2$ | $P_1$ | $\Delta P_1$ | $P_2$ | $\Delta P_2$ |
|---|---|---|---|---|---|---|---|---|
| Yellow fin tuna | 1 | 372 | 68 | 112 | 0.056,513 | 0.000,187 | 0.117,337 | 0.000,178 |
| | 2 | 372 | 110 | 119 | 0.050,894 | 0.000,520 | 0.067,321 | 0.000,497 |
| | 3 | 374 | 89 | 125 | 0.033,360 | 0.000,457 | 0.057,059 | 0.000,587 |
| | 4 | 375 | 65 | 88 | 0.048,106 | 0.000,205 | 0.081,198 | 0.000,192 |
| | 5 | 370 | 54 | 104 | −0.020,591 | 0.000,504 | −0.014,521 | 0.000,836 |
| | 6 | 375 | 103 | 151 | 0.126,662 | 0.000,057 | 0.130,032 | 0.000,379 |
| | 7 | 377 | 101 | 123 | 0.040,085 | 0.000,497 | 0.062,193 | 0.000,534 |
| | 8 | 167 | 14 | 35 | 0.048,167 | −0.000,074 | 0.053,540 | 0.000,610 |
| | 9 | 231 | 32 | 38 | 0.089,037 | −0.000,170 | 0.025,569 | 0.000,489 |
| | 10 | 376 | 56 | 79 | 0.037,993 | 0.000,194 | 0.054,475 | 0.000,268 |
| | 11 | 373 | 106 | 124 | 0.040,292 | 0.000,544 | 0.019,795 | 0.000,783 |
| | 12 | 373 | 61 | 99 | 0.113,371 | −0.000,169 | 0.163,826 | −0.000,166 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 372 | 6 | 7 | −0.007,333 | 0.000,083 | 0.004,356 | 0.000,027 |
| | 2 | 372 | 5 | 4 | −0.005,068 | 0.000,063 | −0.005,209 | 0.000,057 |
| | 3 | 374 | 6 | 11 | −0.002,137 | 0.000,054 | 0.015,915 | −0.000,006 |
| | 4 | 375 | 9 | 5 | −0.000,854 | 0.000,068 | −0.007,642 | 0.000,076 |
| | 5 | 370 | 6 | 15 | −0.001,464 | 0.000,052 | 0.021,945 | −0.000,009 |
| Big eye | 6 | 375 | 19 | 25 | 0.004,719 | 0.000,110 | 0.019,025 | 0.000,076 |
| tuna | 7 | 377 | 4 | 23 | −0.000,546 | 0.000,031 | −0.004,117 | 0.000,183 |
| | 8 | 167 | 1 | 5 | −0.000,756 | 0.000,045 | 0.008,720 | 0.000,074 |
| | 9 | 231 | 0 | 7 | 0 | 0 | 0.037,560 | −0.000,193 |
| | 10 | 376 | 14 | 33 | 0.020,319 | −0.000,009 | 0.040,479 | 0.000,018 |
| | 11 | 373 | 3 | 11 | 0.005,710 | −0.000,009 | −0.004,312 | 0.000,102 |
| | 12 | 373 | 5 | 11 | 0.003,808 | 0.000,015 | 0.005,579 | 0.000,049 |
| | 1 | 372 | 1 | 1 | −0.002,265 | 0.000,019 | 0.002,066 | −0.000,004 |
| | 2 | 372 | 6 | 8 | 0.000,366 | 0.000,041 | 0.004,016 | 0.000,036 |
| | 3 | 374 | 21 | 20 | 0.022,028 | 0.000,032 | 0.024,319 | 0.000,013 |
| | 4 | 375 | 14 | 10 | 0.015,029 | 0.000,019 | 0.022,064 | −0.000,046 |
| | 5 | 370 | 25 | 45 | 0.051,731 | −0.000,097 | 0.058,179 | 0.000,014 |
| Alba- | 6 | 375 | 14 | 31 | 0.023,517 | −0.000,026 | 0.063,403 | −0.000,117 |
| core | 7 | 377 | 16 | 21 | 0.032,435 | −0.000,059 | 0.030,046 | −0.000,116 |
| | 8 | 167 | 7 | 6 | 0.012,208 | 0.000,104 | 0.000,464 | 0.000,208 |
| | 9 | 231 | 1 | 2 | −0.000,472 | 0.000,023 | −0.003,580 | 0.000,068 |
| | 10 | 376 | 6 | 12 | 0.010,410 | −0.000,013 | 0.002,827 | 0.000,070 |
| | 11 | 373 | 2 | 6 | 0.001,716 | 0.000,005 | 0.009,490 | −0.000,008 |
| | 12 | 373 | 2 | 11 | 0.003,646 | −0.000,005 | 0.022,223 | −0.000,040 |

Note : Constants, in which the gradient is put out of consideration, can be easily estimative from m and $N_1+N_2$ or $N_1$ and $N_2$.

Constants per lot of different length, in which the gradient is taken into consideration, can be computed by the following methods :

1) Constants per hook, in which the difference in occupied-rate of hooks located at the different depth levels is put out of consideration

$$P_0 = \frac{P_1+P_2}{2} \qquad \Delta P = \frac{\Delta P_1+\Delta P_2}{2}$$

2) Constants per basket.

$$P = 2\,(P_1+P_2) \qquad \Delta P = 2\,(\Delta P_1+\Delta P_2)$$

3) Constants per lot of other length: At first, $\Delta P$ is computed from the following relation : ($\Delta P$ per 10 baskets) = 4 ($\Delta P$ per 5 baskets) = 25 ($\Delta P$ per 2 baskets) = 100($\Delta P$ per basket). Then $P_0$ is computed adopting the below mentioned relation : $N = \Sigma(P_0+i\Delta P)$.

## 6. Supplement for decoding

The maximum length treated in the first report of this series was limited to the width of 250 consecutive baskets which did not reach the whole length of a row of gears. But another series in which a width of 10 consecutive baskets is adopted as the unit-length added, it gets possibility of covering the whole length of a

row of gears. And this also makes it easier to deduce the number of schools distributed in a row, because the small deviations are averaged to disappear together with the following reasons: let us set that $S$ schools are distributed in a whole row of gears. And when all intervals between any two schools do not take the same width, the peaks of the observed-values, except the first one which begins from $k=0$, have to be observable as frequently as the number of combinations picking up 2 from $S$, which is $\frac{S(S-1)}{2}$; while when all schools are arranged spaced at regular intervals, $(S-1)$ peaks may be observable. Accordingly, if $\Theta$ peaks are observable, maximum number of schools contained is expected to be $(\Theta+1)$, while minimum, $s$, is $\frac{1+\sqrt{1+8\Theta}}{2}$. But if $k$ of respective peaks of the observed-values are set to be $k_1, k_2, \cdots k_i \cdots k_j \cdots k_l \cdots$ and $k_n$, and $k_l = k_i + k_j$, moreover number of $k$ frequently showing such relation is set to be $\theta$, it is also highly probable that $(\Theta+1-\theta)$ must be one of the key numbers of some significance upon the estimation of number of schools hooked in a row, perhaps indicating the most probable number.

## Results of the Spacing Analysis

It is one of the principal subjects of this report to show the results of the correlation analysis. But it is presupposable that the relation of the hooked-positions between the individuals of the different species to consider with large scale can easily be found out from the distribution patterns of respective species, although the relation of the hooked-positions within a short range is hardly assumable from them. Therefore, the tendencies of the deviations of the observed-values of respective species represented in the results of spacing analysis, which is constructed on the same basic idea as in the correlation analysis, should be examined as a preliminary step and suitable attention has to be paid to the tendencies of the deviation of the observed-values, for the purpose of analyzing the correlation easily and clearly. Also, it is one of the principal subjects of this report to show the actually analyzed examples adopting the more advanced methods——the interval analysis and the arrangement one. Therefore, I must examine what kind of superficial and fundamental differences in the decoded patterns are caused by the difference in the basic assumptions between the spacing method and the newly added ones. Owing to the above-mentioned reasons, I can not help describing, even if not so in detail, about the results of the spacing analysis.

On the other hand, if the results of the spacing analysis were described for the purpose of finding out the general tendencies of the distribution pattern of respective species, the descriptions should be arranged species by species; while when they are shown as one of the auxiary materials for the analysis of the correlation, it seems to be far more convenient and reasonable to be arranged operation by operation. And the descriptions are arranged following this reason.

For convenience' sake of representation, the series of analyses, in which 10 consecutive basket width is adopted as the unit-length, is called Series Ⅰ; that of five consecutive basket width is Series Ⅱ; that of two consecutive basket width is Series Ⅲ; that of one basket width is Series Ⅳ; while that of one hook-interval width is Series Ⅴ, respectively. And the scarcity of catch makes it impossible to get the figure with less risk introducing severe influence of accidental error into decoding; therefore, when catch by a row is poorer than five individuals, all series of analyses are omitted; when that is neither poorer than six nor richer than 10, all the series except Series Ⅰ are omitted; when that is neither poorer than 11 nor richer than 15, other series than Series Ⅰ and Ⅱ are omitted; when that is neither poorer than 16 nor richer than 20, Series Ⅳ and Ⅴ are omitted; while when that is neither poorer than 21 nor richer than 25, Series Ⅴ is omitted.

In all diagrams showing the results of the spacing analysis, solid circles represent the observed-values; while the open ones show the theoretical values computed from Formulae (1) and (2) (for Series Ⅰ～Ⅳ) or Formulae (3) and (4) (for Series Ⅴ).

## 1. Exposition of particular example

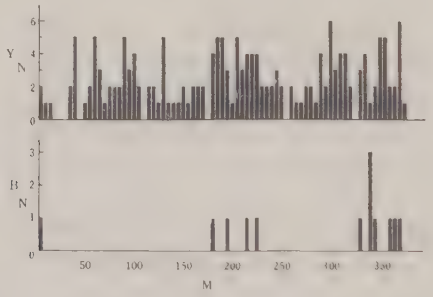



Fig. 2. Distribution of each species in each of five consecutive baskets in Example 1.
Abbreviations (common to Figs. 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22 and 24)
Y : Yellow-fin tuna
B : Big-eye tuna
A : Albacore
M : Basket number counted from the initial point of hauling
N : Number of the individuals caught by respective consecutive five baskets; therefore, pay special attention to the fact that, when the section is fully occupied, this value should be 20.

### Example 1

*Yellow-fin tuna* : From the diagram of Series Ⅰ, we may be unable to deduce out any fact except that the hooked-individuals are, generally speaking, distributed almost by chance. But high occupied-rate due to good total catch and less number of lots resulted to show high observed-values. Accordingly, the confidence zone of the esti-

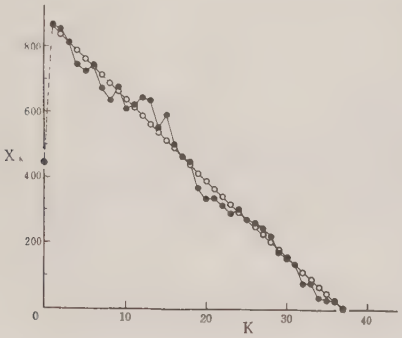



Fig. 3—Y—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 1, Series Ⅰ : unit is 10 consecutive basket width $=ca.$ 2 km).

Notes (common to Figs. 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 23 and 25) : Solid circles show the observed-values ; while open ones indicate the estimated ones.

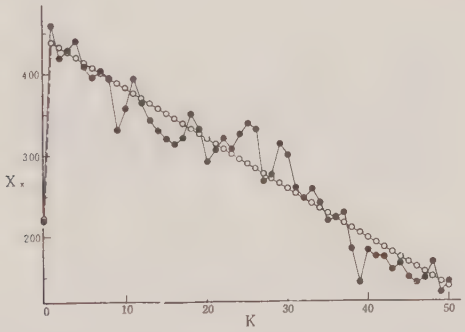
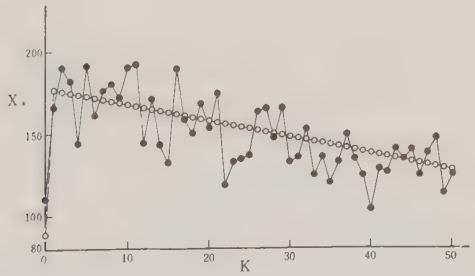



Fig. 3—Y—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 1, Series Ⅱ : unit is 5 consecutive basket width $=ca.$ 1 km)




.Fig. 3—Y—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 1, Series Ⅲ : unit is 2 consecutive basket width $=ca.$ 0.4 km).

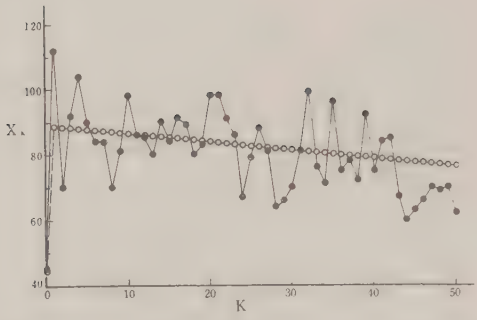



Fig. 3—Y—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 1, Series Ⅳ : unit is 1 basket width=*ca.* 0.2 km).

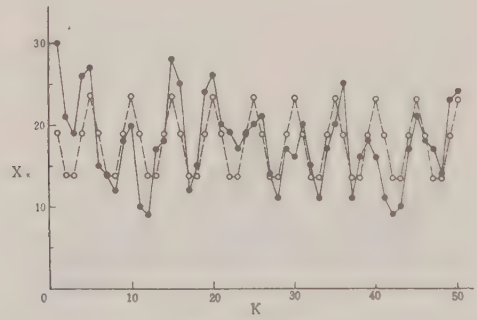



Fig. 3—Y—Ⅴ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 1, Series Ⅴ : unit is one hook-interval width= *ca.* 40 m).

mated-values is thought to be narrow. Therefore, some significance and consideration can be given to most of or at least some of the above-mentioned small deviations, although, at the present stage of this study, I can not yet find out any examination method determining how largely biased values are safely said to be different significantly. And if so, the following facts come to be deducible. The pattern most clearly suspected from the diagram of Series Ⅰ is that there are three groups of schools, adjoining centers of which are spaced by a width as long as from 110 (= 20 km) to 180 baskets (= 35 km) one another while the centers of the distal pair of schools are spaced by a width as long as 250 baskets (= 50 km) each other. And they may seem to indicate the groups of the heavily-occupied lots found at the positions around the 80th, the 200th and the 350th baskets, respectively (the *xth* basket indicates the position where the *xth* basket counting from the beginning of hauling is located, in which the basket number is counted as one function of more than 2.5

while less than 5.0 and more than 7.5 while less than 10.0 as a unit and cut away the rest). Besides, a peak of the observed-value at $k = 6$ lots (lot = 10 consecutive baskets) in the diagram of Series Ⅰ, which is more clearly represented in the diagram of Series Ⅱ at $k = 11$ and in Series Ⅲ at $k =$ a little shorter than 30, suggests the presence of other obscure schools, the centers of which are spaced by a width as long as 60 baskets (= 12 km) from some of the above-mentioned schools. The schools pointed out here seem to indicate the groups of heavily-occupied lots found at the positions around the 140th and the 300th baskets. But the significance of the presence of the former is somewhat doubtful. The deviations of the short periodicity found in the observed-values of the diagrams of Series Ⅱ, Ⅲ and Ⅳ seem to show the presence of some structures of the subordinate orders. The analysis of Series Ⅴ shows that maximum width of the elemental cluster is estimated as long as a basket width (=*ca.* 200 m)——*i.e.*, the hooks spaced by a length shorter than a basket from any occupied one are occupied more frequently than expected from the chance distribution.

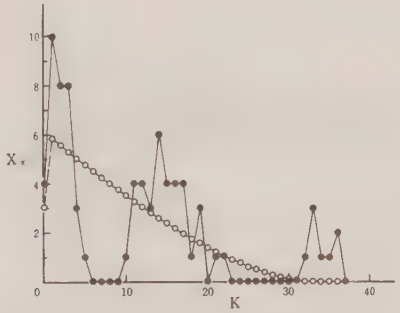



Fig. 3—B—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 1, Series Ⅰ : unit is 10 consecutive basket width =*ca.* 2 km).

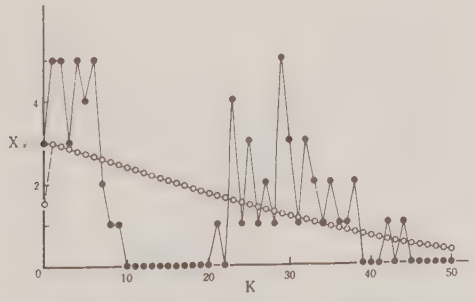



Fig. 3—B—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 1, Series Ⅱ : unit is 5 consecutive basket width =*ca.* 1 km).

*Big-eye tuna* : The diagram of Series I indicates clearly that, as easily noticeable from Fig. 2, there are three distinct schools, among which the centers of the adjoining pairs are spaced by a width as long as *ca.* 15 lots (= 30 km) (lot = 10 consecutive baskets) one another while the distal pair is by *ca.* 35 lots (70 km). And the diagram of Series II may show that they are constituted of many clusters of subordinate orders, but any significance and description can hardly be given to it, because the number of the individuals constituting each subordinate cluster is supposed to be not so many. And I must record here, for the purpose of calling attention, that the words "school or cluster" conveniently used indicate frequently even a single hooked-individual, especially in such a case of extremely low occupied-rate as this, although whether they are swimming solitary or a single individual unfortunately hooked from many individuals swimming together as a school is the other problem.

*Albacore* : Omitted from the analysis, because no more than two individuals are hooked by a whole row of gears.

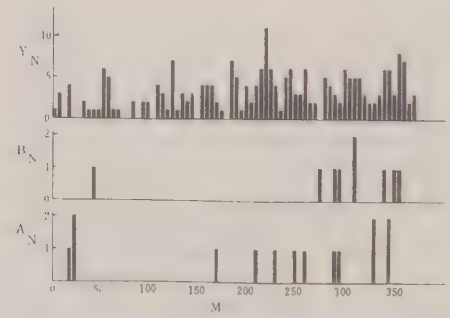



Fig. 4. Distribution of each species in each of five consecutive baskets in Example 2.

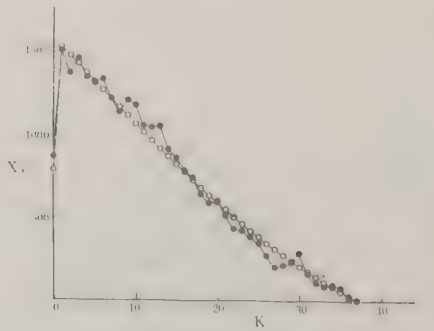



Fig. 5 —Y— I. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 2, Series I : unit is 10 consecutive basket width = *ca.* 2 km).

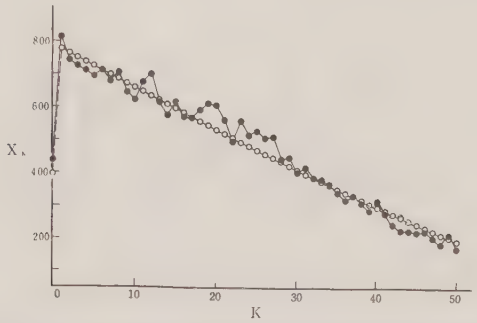



Fig. 5—Y—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 2, Series Ⅱ : unit is 5 consecutive basket width=*ca.* 1 km).

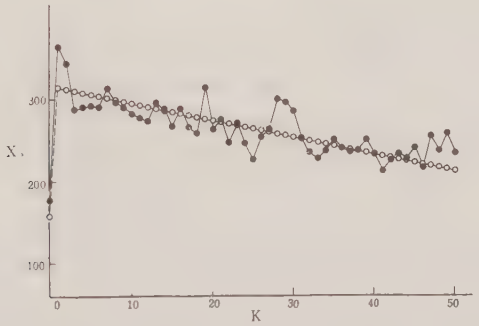



Fig. 5—Y—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 2, Series Ⅲ : unit is 2 consecutive basket width=*ca.* 0.4 km).

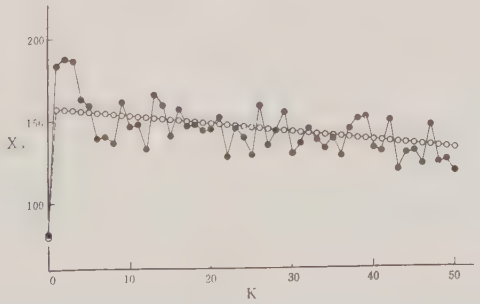



Fig. 5—Y—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 2, Series Ⅳ : unit is 1 basket width=*ca.* 0.2 km).

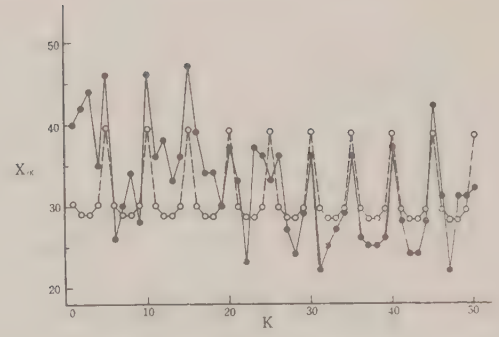



Fig. 5—Ⅴ—Ⅴ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 2, Series Ⅴ : unit is one hook-interval width = *ca.* 40 m).

## Example 2

*Yellow-fin tuna* : Rather strong gradient of distribution is suspected from Fig. 4. And the influence of it is excluded in all series of estimated-values. The analysis of Series Ⅰ shows that less than five schools are arranged closely. Besides, the presence of two other schools, the centers of which are spaced by a width as long as about 200 (= 40 km) or 300 baskets (= 60 km) from the center of the above-mentioned group of schools, is suggested, of which the significance of the former is low. Therefore, from Fig. 4 together with Table 12, the position of schools detected lastly is assumed to be around the 50th basket. But the positional relation between schools, the centers of which are spaced by a width shorter than 250 baskets (= 50 km) one another, is represented more clearly in the diagram of Series Ⅱ, in which the peaks of the observed-values are located at $k$ = 12,19 and 25 lots (lot = 5 consecutive baskets). Therefore, the group of schools detected from the first series seems to be constituted of less than four schools, the centers of which, including that located at the position around the 50th basket, are spaced by the width as long as about 60 (= 12 km), 95 (= 19 km) or 125 baskets ( =25 km) one another. And one of these schools is set to be hooked at the position around the 220th basket, because a most heavily-occupied lot is observable at the 220th basket. Therefore, the expectant positions of schools, where are spaced by the width of respective key-lengths mentioned above from the 220th basket, are estimated to be the 95th, the 125th, the 160th, the 280th, the 315th and the 345th baskets. And in examining Fig. 4 and Table 12, I found that individuals were heavily occupying all of the expectant positions except the first one. Therefore, the above-mentioned positions are thought to indicate the positions of schools. On the analyses of Series Ⅲ and Ⅳ, besides the above-mentioned pattern, nothing can be drawn out other than the fact that heavily-occupied baskets are a little frequently observable at the positions spaced by a width shorter than five baskets from any occupied basket especially from heavily-occupied one, ——*i.e.*, contagiousness reaches a width as long as five baskets (= 1 km). The

analysis of Series Ⅴ shows that contagiousness reaches a width as long as one basket (= 0.2 km) and that the pairs of individuals caught by the hooks spaced by the width neither shorter than two baskets (= 0.4 km) nor longer than five baskets (= 1 km) are more frequently observable than expected from chance distribution. For the meanings of the latter fact, whether it shows the relation within the same elemental clusters or between them is uncertain, but the analyses of Series Ⅲ and Ⅳ suggest that it seems to be more natural to consider that this fact also indicates the relation within the same elemental clusters —— *i.e.*, the presence of heavily-occupied part covering a width as long as five baskets (= 1 km) is suggested as one of the most clearly represented characteristics of the distribution pattern of this example, or in other words, strong school-formation covering not so wide range is suggested. And this result is strongly supported by the fact that there are more than seven lots constituted of more than five individuals and covering a width as long as or shorter than five baskets.

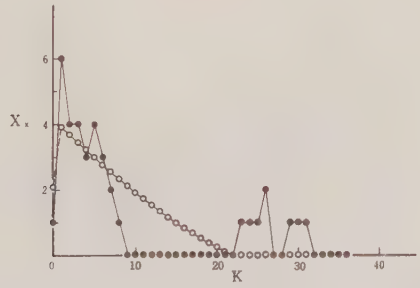



Fig. 5—B—I. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 2, Series I : unit is 10 consecutive basket width =*ca.* 2 km).

*Big-eye tuna* : The diagram of Series I reveals that there are some schools, the centers of which are spaced by the width as long as 5, 25 and 30 lots (lot = 10 consecutive baskets = 2 km) one another. Accordingly, the number of schools is estimated to be three at minimum while four at maximum. But it is highly probable that the peaks observable at $k = 5$ and 25 mean the same fact, because $5+25 = 30$. Therefore, the most probable number of schools is thought to be three. From Fig. 4, it becomes clear that the above-mentioned schools indicate a single or group of the individuals hooked at the 50th, around the 300th and the 350th baskets, respectively.

*Albacore* : The severe deviation due to poor catch and to scattered structure makes it impossible to deduce from the diagram of Series I nothing else than that the hooked-individuals are scattered self-spacingly all over a whole row of gears, against the fact that hooked population is clearly constituted of three individuals aggregated rather strongly and hooked at the 20th basket and of a widely dispersed school covering

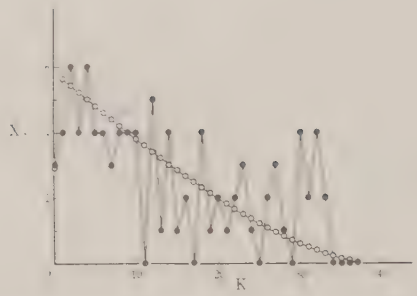


Fig. 5—A—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 2, Series Ⅰ : unit is 10 consecutive basket width = *ca.* 2 km).

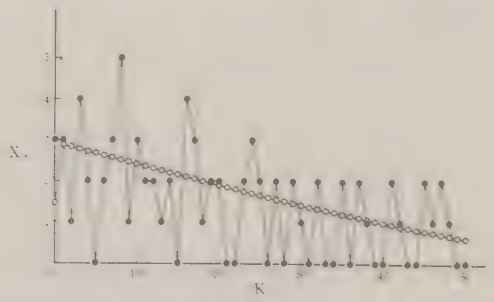


Fig. 5—A—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 2, Series Ⅱ : unit is 5 consecutive basket width = *ca.* 1 km).

a space from the 170th to the 350th basket; while the deviation of short periodicity disappears when the unit-length under consideration is elongated into from three to five times as long as the unit-length adopted in the analysis of Series Ⅰ, and the diagram showing the pattern coinciding well with that expected from Fig. 4 comes to be obtainable.

### Example 3

*Yellow-fin tuna* : The distribution of the individuals shows strong gradient. But the presence of a single school of very weak contagiousness covering a space as wide as from 130 to 180 baskets (= 25~35 km) is discernible, which seems to be located in the range from the 190th to the 315th basket or including the part from the 140th to the 190th basket. And the structure of subordinate order is deducible from the short-periodic deviation of the observed-values in Fig. 7—Y—Ⅱ, which indicates that the peaks of the observed-values are located at the positions around $k$ = 3, 7, 12, 16, 18

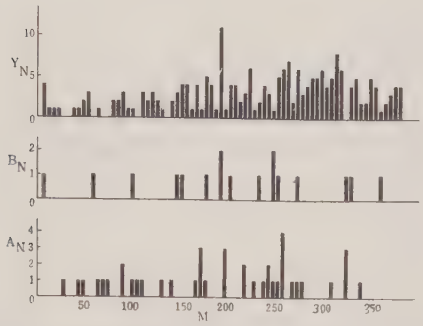



Fig. 6. Distribution of each species in each of five consecutive baskets in Example 3.

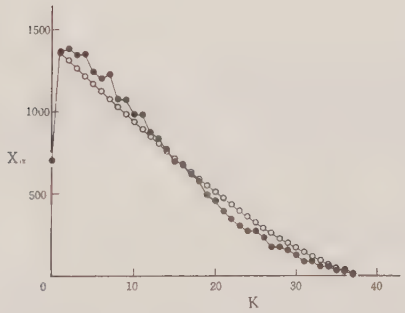



Fig. 7—Y—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 3, Series Ⅰ : unit is 10 consecutive basket width = *ca.* 2 km).

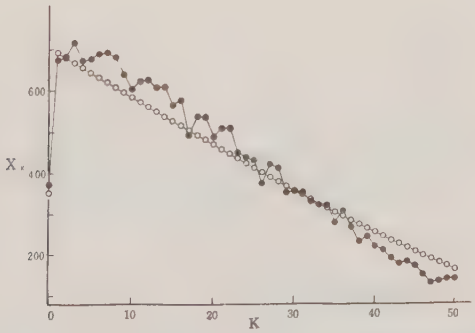



Fig. 7—Y—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 3, Series Ⅱ : unit is 5 consecutive basket width = *ca.* 1 km).

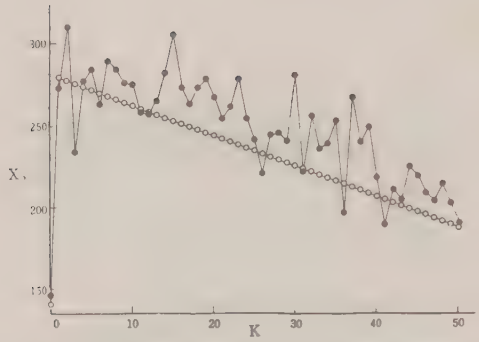



Fig. 7—Y—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 3, Series Ⅲ : unit is 2 consecutive basket width=*ca.* 0.4 km).

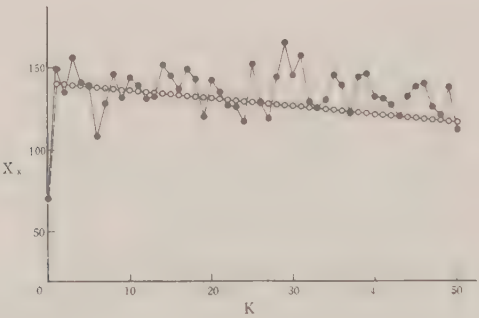



Fig. 7—Y—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 3, Series Ⅳ : unit is 1 basket width=*ca.* 0.2 km).

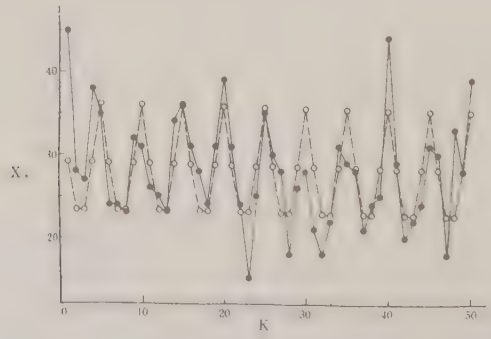



Fig. 7—Y—Ⅴ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 3, Series Ⅴ : unit is one hook-interval width =*ca.* 40 m).

and 21 lots (lot = five consecutive baskets) among which the significance of the third one is somewhat doubtful (if supposed to cover longer, one or two more peaks are observable in which the first one, $k = 27$, is the most distinct). Therefore, the number of schools of the subordinate order is estimated to be from three at minimum to seven at maximum. And a most distant pair of the subordinate schools is estimated to be spaced by the width as long as 105 baskets (= *ca.* 20 km) each other. But the position of the center of the subordinate school hooked in the hindmost part of a school is set to be the 310th basket, consequently the subordinate school hooked in the foremost part of a school is set to be located at the 205th basket. Next, for the purpose of finding out the positions of the other schools of the subordinate order located between them, the expectant positions of their centers are estimated as follows: the 220th, the 230th, the 240th, the 250th, the 265th, the 275th, the 285th and the 295th baskets, where are spaced by respective $k$ mentioned above from each of the terminal schools of the subordinate order. But there is no definite method to distinguish the actual sub-schools from the imaginal ones. The diagram of Series Ⅱ shows not so clearly the feature of the school-formation of the above-mentioned subordinate order, because it is influenced by the structure of the more subordinate orders. The deviation of the short periodicity shows that clusters of this order are frequently observable spaced by the width of $5A$ lots (= $2A$ km) (lot = two consecutive baskets and $A$ is a positive integer) one another. The analysis of Series Ⅴ adds such information that the elemental clusters seem to cover a space as wide as or narrower than a basket width, especially a hook-interval.

*Big-eye tuna* : The diagram of Series Ⅰ suggests that as many individuals as expected from chance distribution are caught by any occupied-lot, while these occupied-lots are so self-spacingly distributed that less individuals than or at most as many individuals as expected are hooked in the lots spaced by a width as long as or shorter than three lots from any occupied one, but the occupied-lots are frequently located spaced by the widths about 2, 5, 9, 13, 17, 21, 24, 26, 31 and 35 lots (lot = 2 km)

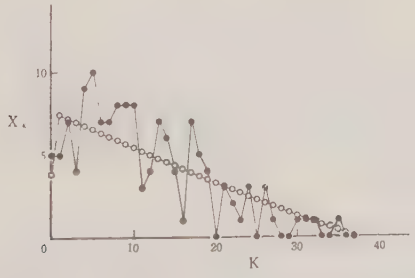



Fig. 7—B—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 3, Series Ⅰ : unit is 10 consecutive basket width = *ca.* 2 km).

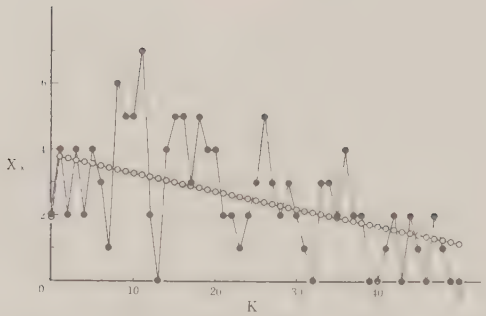



Fig. 7—B—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 3, Series Ⅱ : unit is 5 consecutive basket width $=ca.$ 1 km).

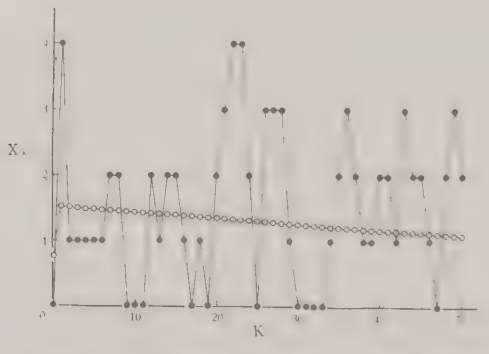



Fig. 7—B—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 3, Series Ⅲ : unit is 2 consecutive basket width $=ca.$ 0.4 km).

one another. Therefore, the number of schools distributed in a row is guessed out to be from 5 to at most 11. But among them, a most probable number of schools is 10, because sums of two other $k$ frequently take 26. And the same but more detailed pattern is suggested from the diagram of Series Ⅱ. And the diagram of Series Ⅲ may seem to allude to the subordinate or more detailed pattern, but no significance can be given to it because of being afraid of the influence of accidental error introduced by low observed-values.

*Albacore* : General tendency of the deviations of the observed-values of Series Ⅰ shows that the population seems to be constituted of single school covering a wide range. But, the small deviations cause the peaks of the observed-values located at $k$ = 2, 4, 6, 12, 15, 17, 19, 21, 23, 25, 27, and 29 lots (lot = 10 consecutive baskets). Therefore, the basic pattern of the subordinate order of this school is thought to be

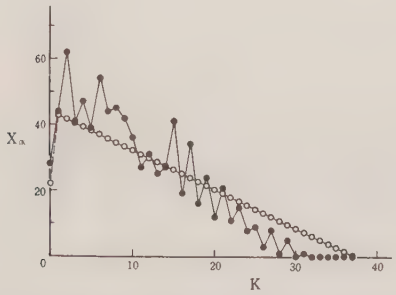



Fig. 7—A—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 3, Series Ⅰ : unit is 10 consecutive basket width = *ca.* 2 km).

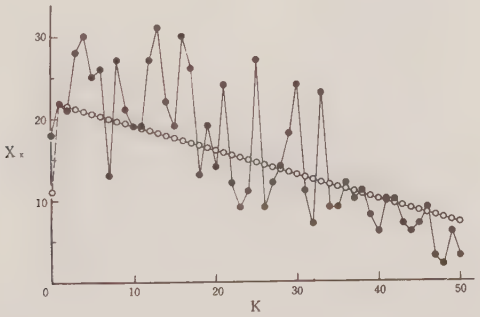



Fig. 7—A—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 3, Series Ⅱ : unit is 5 consecutive basket width = *ca.* 1 km).

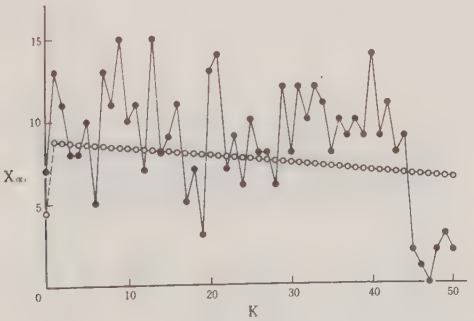



Fig. 7—A—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 3, Series Ⅲ : unit is 2 consecutive basket width = *ca.* 0.4 km).

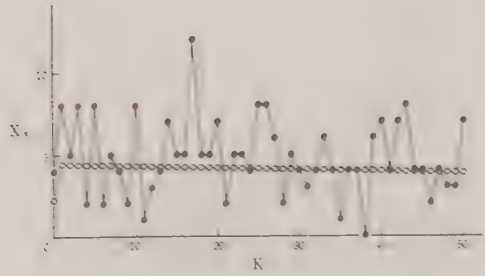


Fig. 7—A—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 3, Series Ⅳ : unit is 1 basket width=*ca.* 0.2 km).

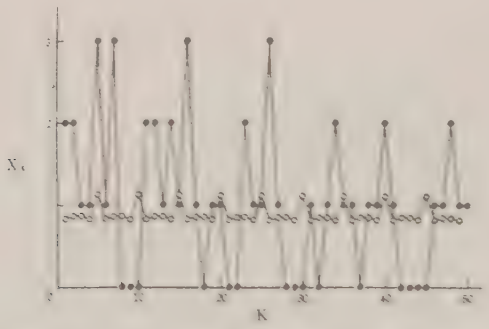


Fig. 7—A—Ⅴ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 3, Series Ⅴ : unit is one hook-interval width=*ca.* 40 m).

13 or less occupied-lots, especially heavily occupied ones, distributed showing two-lot periodicity, to which some less heavily-occupied lots are added.

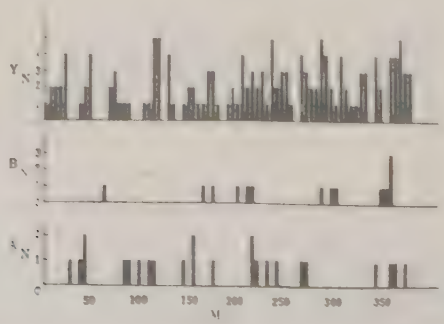


Fig. 8. Distribution of each species in each of five consecutive baskets in Example 4.

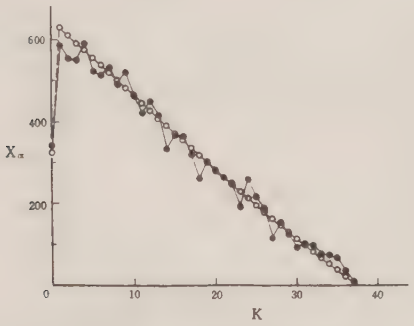



Fig. 9—Y—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 4, Series Ⅰ : unit is 10 consecutive basket width=*ca.* 2 km).

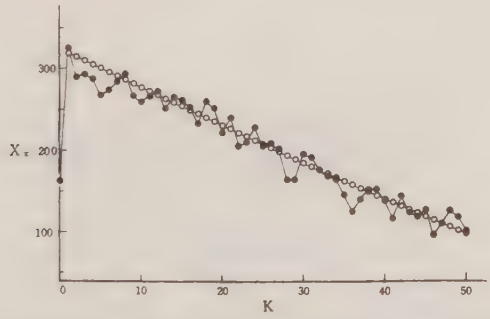



Fig. 9—Y—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 4, Series Ⅱ : unit is 5 consecutive basket width =*ca.* 1 km).

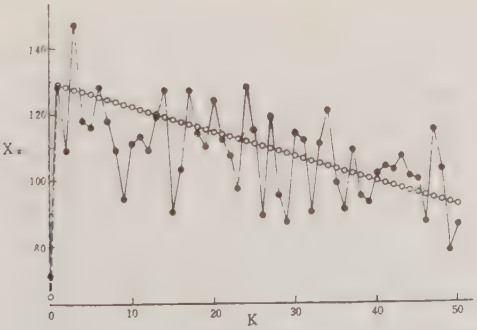



Fig. 9—Y—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 4, Series Ⅲ : unit is 2 consecutive basket width=*ca.* 0.4 km).

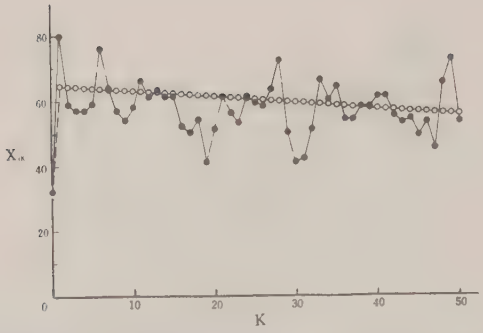



Fig. 9—Y—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 4, Series Ⅳ : unit is 1 basket width $=ca.$ 0.2 km).

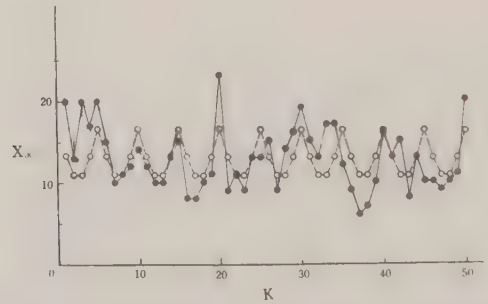



Fig. 9—Y—Ⅴ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 4, Series Ⅴ : unit is one hook-interval width $=ca.$ 40 m).

**Example 4**

*Yellow-fin tuna* : The deviations of the observed-values in the diagrams of Series Ⅰ and Ⅱ show essentially the same fact that the number of individuals hooked in respective lots (lot = 10 consecutive baskets) is not so different from the number expected from chance distribution but heavily-occupied lots are scattered throughout a whole row spaced by a width of $4A$ lots ($A$ is a positive integer but not so large) one another, while the number of individuals hooked by the lots spaced by the width shorter than four lots from any occupied one especially from heavily-occupied one does not reach the value expected when respective occupied-lots are arranged by chance. Therefore, the distribution pattern is decoded to be as follows: many schools of narrow width are evenly scattered throughout a whole row. A little irregular periodicity of three-lot width observable in the results of analysis of Series Ⅲ and six-lot periodicity in the analysis of Series Ⅳ show the same fact that the occupied baskets, especially heavily-occupied ones, are frequently observable spaced by a width

of 6*A* baskets or thereabout one another. The analysis of Series Ⅴ also supports this six-basket periodicity, besides the fact that the widths of the elemental clusters do not exceed a length little longer than a basket.

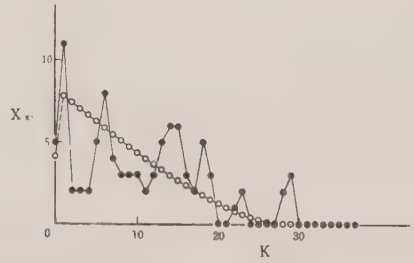



Fig. 9—B—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 4, Series Ⅰ : unit is 10 consecutive basket width =*ca.* 2 km).

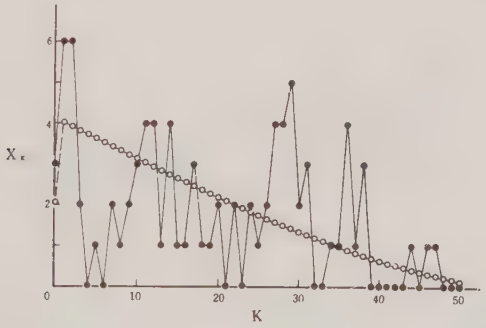



Fig. 9—B—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 4, Series Ⅱ : unit is 5 consecutive basket width= *ca.* 1 km).

*Big-eye tuna* : The diagram of Series Ⅰ shows that there are some schools, the centers of which are spaced by 6, 14, 18, 23 and 29 lots (lot = 10 consecutive baskets and as long as 2 km) one another. Consequently, population seems to contain from four schools at minimum to six schools at maximum. But a most probable number of schools contained is five, because 6 + 23 = 29. And this result coincides well with such a pattern easily deducible from Fig. 8 that individuals are distributed forming five schools constituted of from one to five hooked-individuals and located at the positions respectively around the 65th, the 170th, the 210th, the 290th and the 350th baskets. The same pattern is deducible from the diagram of Series Ⅱ, although it is not so clear to be influenced by irregular deviations of the short periodicities. Nothing can be deducible from the diagrams of the succeeding series, because of the low observed-values and the estimated ones.

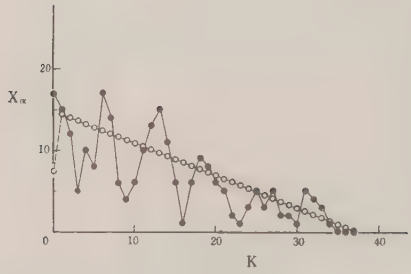



Fig. 9—A—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 4, Series Ⅰ : unit is 10 consecutive basket width = *ca.* 2 km).

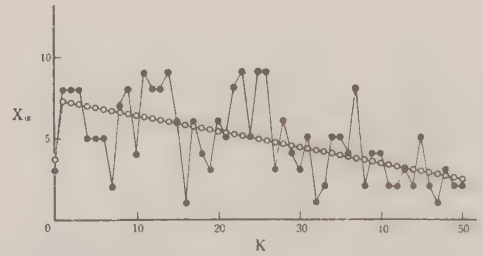



Fig. 9—A—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 4, Series Ⅱ : unit is 5 consecutive basket width = *ca.* 1 km).

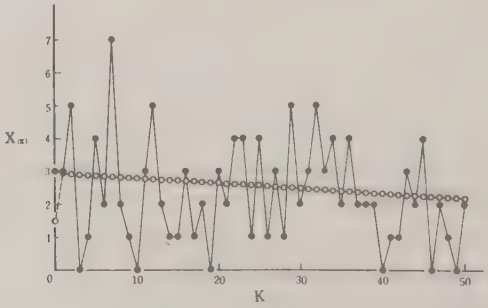



Fig. 9—A—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 4, Series Ⅲ : unit is 2 consecutive basket width = *ca.* 0.4 km).

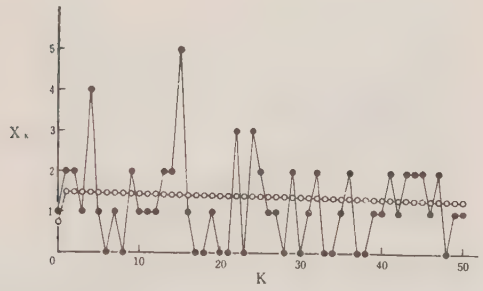



Fig. 9—A—IV. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 4, Series IV : unit is 1 basket width = *ca.* 0.2 km).

*Albacore* : Five peaks of the observed-values, except the first one beginning from $k = 0$, are clearly observable in the diagram of Series I, which are located at $k = 6, 13, 18, 26$ and $31$, respectively. Accordingly, the number of schools contained is estimated to be from four at minimum to six at maximum. But the peaks located at $k = 18$ and $26$, especially the latter, deviate not so severely. Accordingly, it is more probable to assume that four or five schools are scattered throughout a row of gears spaced rather regularly by a width as long as $60A$ baskets one another. It becomes clear that the above-mentioned results decoded from the diagram of Series I are well coincident with the pattern suggested from Fig. 8 : —— the population is constituted of five schools, each of which is constituted of not so many hooked-individuals and located at the positions around the 40th, the 100th, the 155th, the 230th and the 350th baskets, respectively. And the long-periodic deviations of the observed-values in the following series of analyses allude to the same pattern not so clearly to be influenced by the short-periodic deviations. But I do not wish to describe any fact, although the short-periodic one seems to suggest some detailed or subordinate structures, because the population size constituting each of them is not so large, which makes it impossible to give any significance upon them.

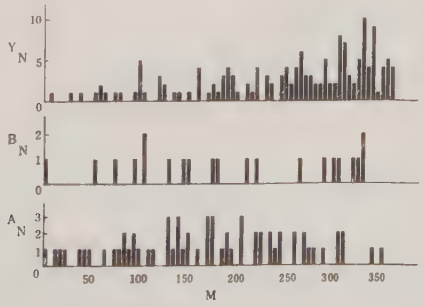



Fig. 10. Distribution of each species in each of five consecutive baskets in Example 5.

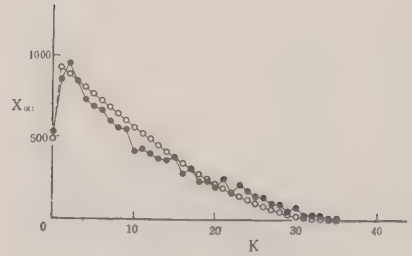



Fig. 11—Y—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 5, Series Ⅰ : unit is 10 consecutive basket width = *ca.* 2 km).

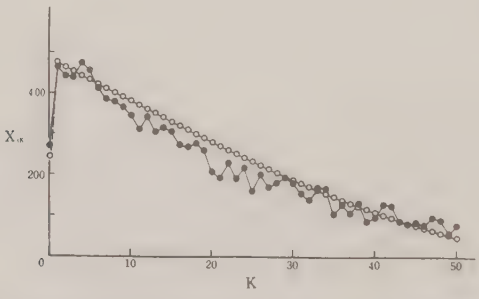



Fig. 11—Y—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 5, Series Ⅱ : unit is 5 consecutive basket width = *ca.* 1 km).

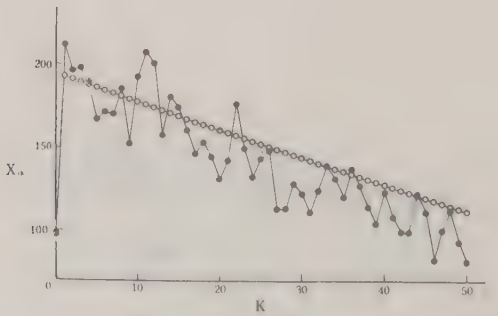



Fig. 11—Y—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 5, Series Ⅲ : unit is 2 consecutive basket width = *ca.* 0.4 km).

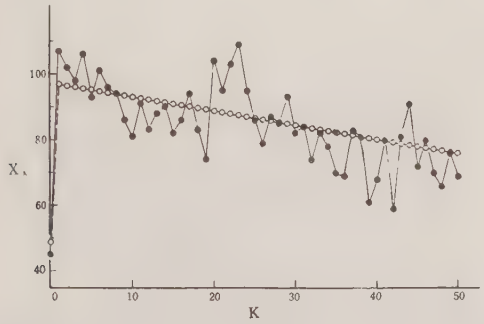



Fig. 11—Y—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 5, Series Ⅳ : unit is 1 basket width=*ca.* 0.2 km).

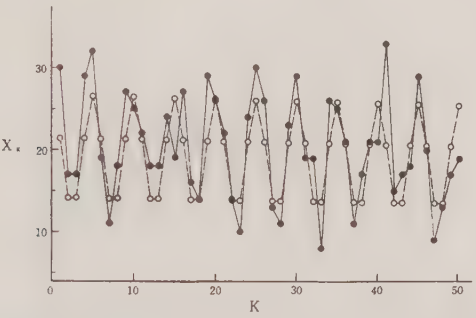



Fig. 11—Y—Ⅴ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 5, Series Ⅴ : unit is one hook-interval width= *ca.* 40 m).

## Example 5

*Yellow-fin tuna* : A strong gradient of the occupied-rate is suggested from Fig. 10. But comparing the observed-values with the estimated ones in which the influence of the gradient is taken into consideration, I found that there were two schools, the centers of which were spaced by a width about as long as 250 baskets (= 50 km) each other. And examining Fig. 10, I found, taking the influence of the gradient into consideration, that the above-mentioned fact indicated the relation between the parts of heavily-occupied lots around the 100th and those around the 350th baskets. The analysis of Series Ⅴ shows that each elemental cluster covers a space as long as or shorter than a basket length, especially one hook-interval.

*Big-eye tuna* : General tendency of the deviations of the observed-values in the diagram of Series Ⅰ suggests that the hooked-individuals are scattered throughout a whole

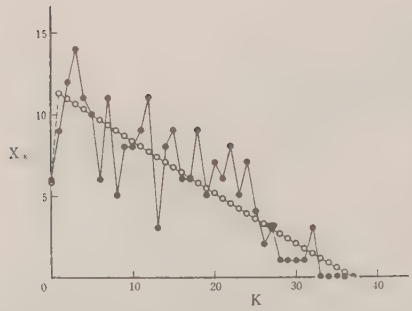



Fig. 11—B—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 5, Series Ⅰ : unit is 10 consecutive basket width = *ca.* 2 km).

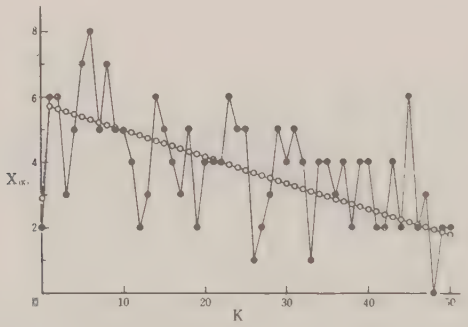



Fig. 11—B—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 5, Series Ⅱ : unit is 5 consecutive basket width = *ca.* 1 km).

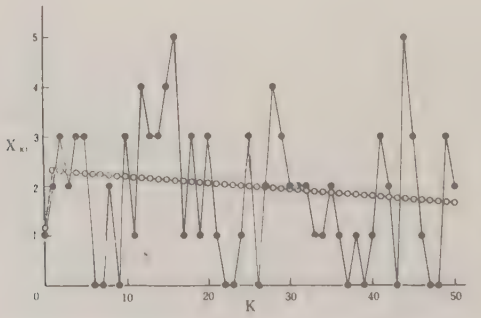



Fig. 11—B—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 5, Series Ⅲ : unit is 2 consecutive basket width = *ca.* 0.4 km).

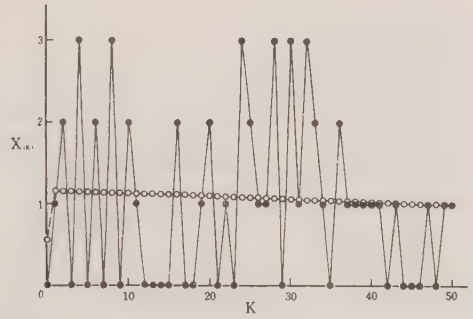



Fig. 11—B—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 5, Series Ⅳ : unit is 1 basket width = *ca.* 0.2 km).

row slightly self-spacingly, in other words forming a single widely dispersed school covering the width of 250 baskets (= 50 km). But examining the more in detail, I found that as many individuals as expected from chance distribution were hooked by the lots preceding to or succeeding to any occupied one, and that the occupied-lots were more frequently observable spaced by 3, 7, 12, 15, 18, 20, 22, 24, 27 and 32 lots (lot = 10 consecutive baskets and as long as 2 km) one another. Accordingly, the number of schools contained is estimated to be from 5 at minimum to 11 at maximum. But the sums of two other $k$ frequently take 27, against the facts that the observed-value at $k = 27$ is not so high comparing with not only the estimated-value at $k = 27$ but also the observed ones at adjoining $k$. Accordingly, the more probable number of schools is 10. And this result also coincides well with the pattern easily deducible from Fig. 10. I do not wish to give any significance upon any fact deduced from the diagrams of Series Ⅱ and Ⅲ, although some subordinate structures may be shown in them, not only because of the low observed-values and the estimated ones but also because each school of subordinate order deducible from these diagrams is constituted of from a single to at most four hooked-individuals.

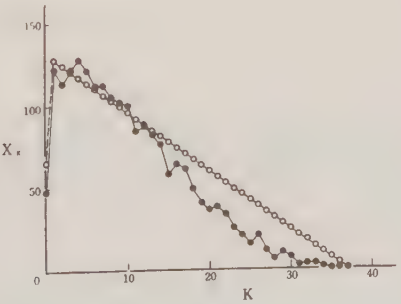



Fig. 11—A—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 5, Series Ⅰ : unit is 10 consecutive basket width = *ca.* 2 km).

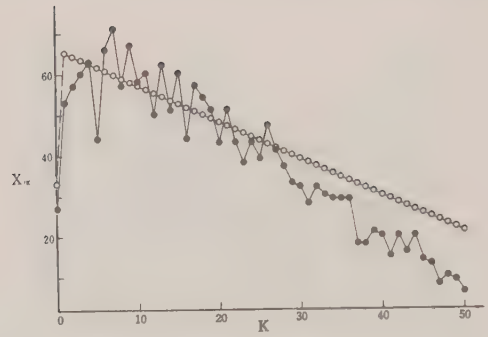



Fig. 11—A—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 5, Series Ⅱ : unit is 5 consecutive basket width = *ca.* 1 km).

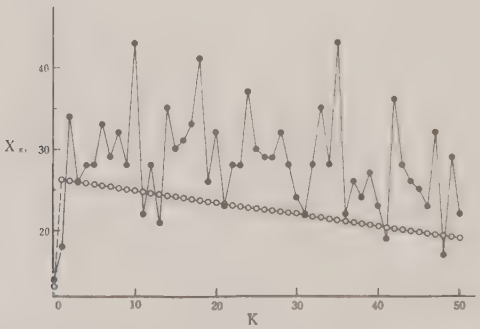



Fig. 11—A—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 5, Series Ⅲ : unit is 2 consecutive basket width = *ca.* 0.4 km).

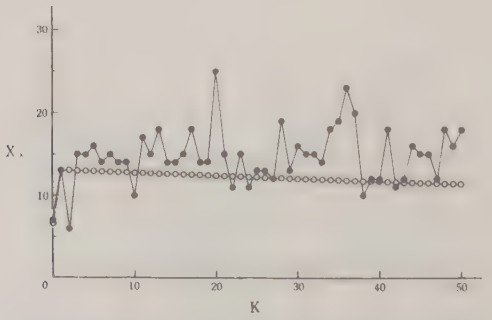



Fig. 11—A—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 5, Series Ⅳ : unit is 1 basket width = *ca.* 0.2 km).

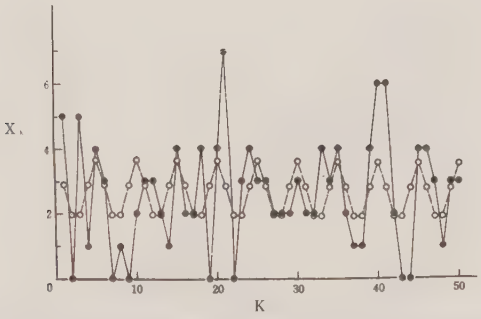



Fig. 11—A—Ⅴ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 5, Series Ⅴ : unit is one hook-interval width = *ca.* 40 m)

*Albacore* : The deviation of the observed-values in Series Ⅰ shows that there is a large school, in which heavily-occupied lots are arranged self-spacingly. And the severe deviation of the observed-values and high observed-values in the following series of analyses suggest the presence of distinct structures of subordinate order of some significance.

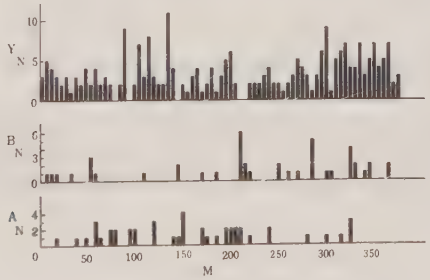



Fig. 12. Distribution of each species in each of five consecutive baskets in Example 6.

## Example 6

*Yellow-fin tuna* : The population, in which heavily-occupied lots are arranged so as to show the periodicity of two lot width as basic structure, contains, to see generally, two groups of schools; their centers are spaced by a width longer than 200 baskets (= 40 km) each other, and these schools seem to be hooked respectively at the positions around the 100th basket and the part latter than the 300th basket. The analysis of Series Ⅱ reveals the relation of the positions of schools within the same group more clearly than the analysis of Series Ⅰ. This diagram also suggests that the smaller group covering the width of 50 baskets is constituted of three schools or thereabout, while the larger one covering the width longer than 75 baskets is consti-

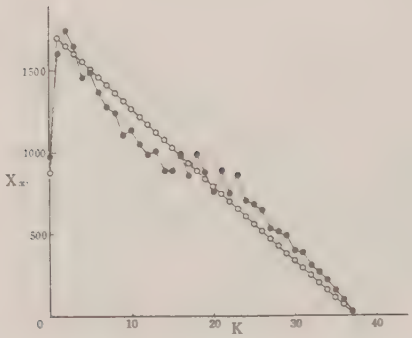



Fig. 13—Y—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 6, Series Ⅰ : unit is 10 consecutive basket width=*ca.* 2 km).

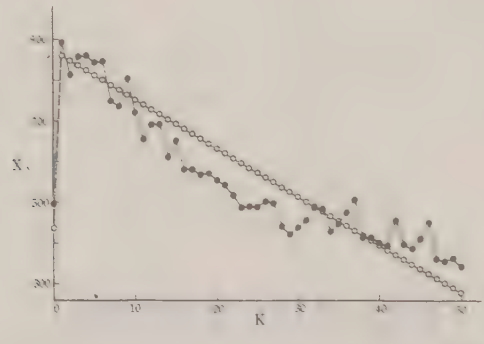



Fig. 13—Y—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 6, Series Ⅱ : unit is 5 consecutive basket width=*ca.* 1 km).

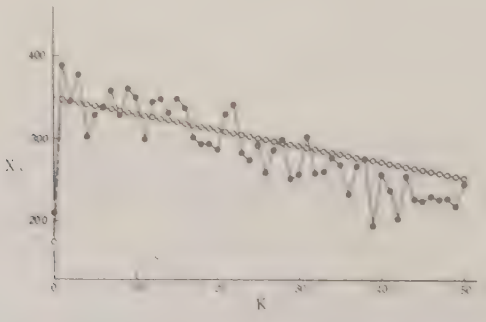



Fig. 13—Y—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 6, Series Ⅲ : unit is 2 consecutive basket width=*ca.* 0.4 km).

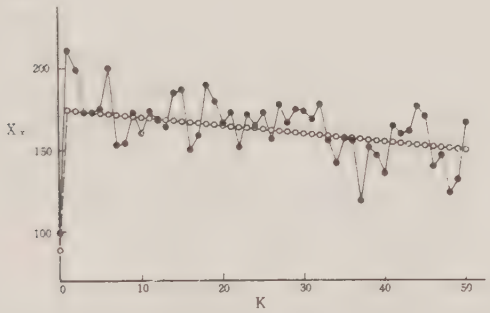



Fig. 13—Y—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 6, Series Ⅳ : unit is 1 basket width=*ca.* 0.2 km).

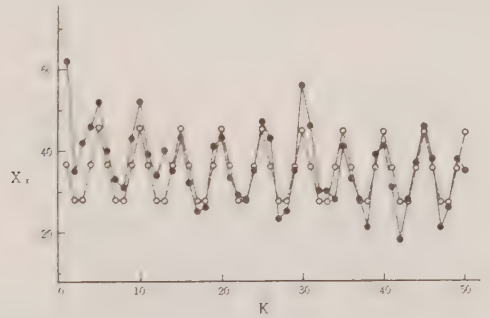



Fig. 13—Y—Ⅴ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 6, Series Ⅴ : unit is one hook-interval width= *ca.* 40 m).

tuted of six schools or thereabout. And examining Fig. 12 and Table 16, I found that the schools constituting the smaller group were estimated to be located at the positions around the 85th, around the 110th and the 135th baskets respectively, while those constituting the larger one were located at the positions around the 275th, the 295th, the 310th, the 320th, the 335th and the 360th baskets respectively. Against the fact that the presence of two other aggregations, each of which is constituted of the population of the same order as those treated in the above, is suggested from Table 16 and the original records, no clear symptom suggesting the presence of them can be found out from the results of the spacing analysis. The analyses of Series Ⅲ and Ⅳ do not add any new information about the distribution pattern. The analysis of Series Ⅴ reveals that the elemental cluster occasionally covers a space as long as two-basket width or thereabout, although the symptoms suggesting such pattern can also be alluded to from the analyses of Series Ⅰ and Ⅳ especially from the latter.

Strictly speaking, this fact means simply that the pairs of individuals spaced by the width shorter than two baskets each other are more frequently observable than expected from chance distribution. But it is not unreasonable to consider that, this fact evolved, there may be many lots covering the range as wide as two baskets or thereabout in which many individuals are hooked. Furthermore, it is highly probable that each school seems to be chiefly constituted of such a lot to which some solitary individuals are added. And many proofs supporting such a structure can easily be found out from Table 16 and the original records.

*Big-eye tuna* : The severe deviations of the observed-values in the diagram of Series Ⅰ suggest the presence of some clear structures. Rather good catch enables the decoded structures to give high significance. That is to say, the general tendency of the deviations of the observed-values shows clearly that there are two groups of schools and that their centers are spaced by the width about as long as 250 baskets or longer each other, and these groups of schools may indicate the groups of individuals hooked in the ranges from the first to the 60th and from the 200th to the

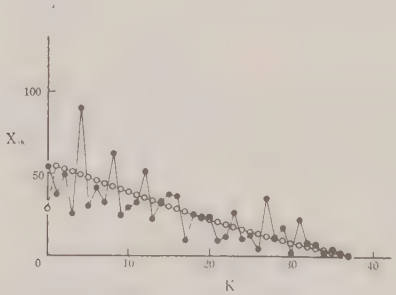



Fig. 13—B—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 6, Series Ⅰ : unit is 10 consecutive basket width = *ca.* 2 km).

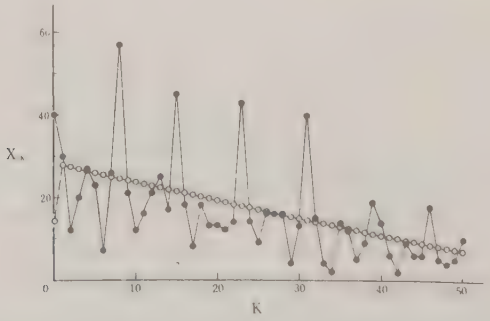



Fig. 13—B—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 6, Series Ⅱ : unit is 5 consecutive basket width = *ca.* 1 km).

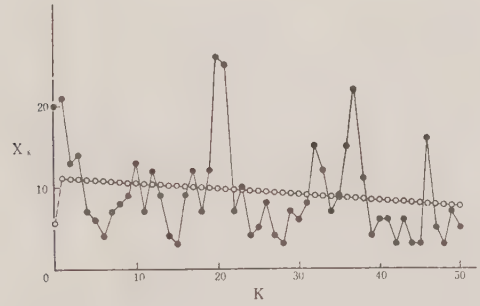



Fig. 13—B—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 6, Series Ⅲ : unit is 2 consecutive basket width = *ca.* 0.4 km).

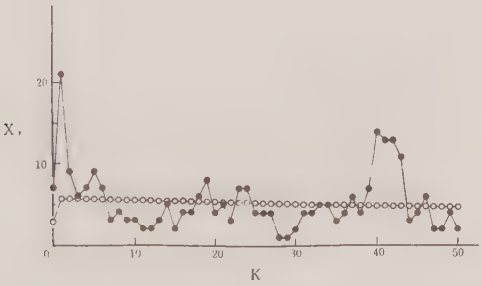



Fig. 13—B—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 6, Series Ⅳ : unit is 1 basket width = *ca.* 0.2 km).

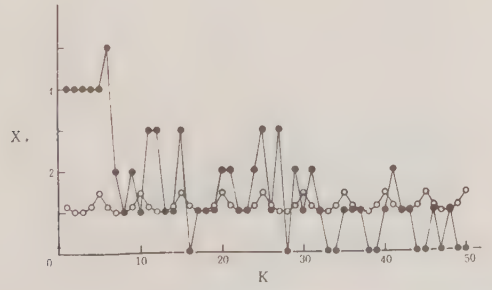



Fig. 13—B—Ⅴ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 6, Series Ⅴ : unit is one hook-interval width = *ca.* 40 m).

hindmost basket respectively. Besides them, the distinct and short-periodic deviation shows that rather strongly aggregated schools are observable spaced by 4, 8, 12, 15, 19, 23, 27, 31, and 35 lots (lot = 10 consecutive baskets and as long as 2 km) one another, among which the significance of the hindmost one is somewhat doubtful —— *i.e.*, showing nearly perfect periodicity of four-lot width. Besides them, not so clear peaks of the observed-values are found at $k$ = 2,6 and 29, among which the hindmost one is as clear as those treated in the above —— at the middle of the above-mentioned ones. Accordingly, the pattern represented most clearly is deduced to be as follows: most of the occupied-lots are arranged spaced by the width as long as $40A$ baskets each other ($A$ is a positive integer but not so large) and some not so heavily-occupied lots are located at some of the positions spaced by 20-basket width from some of the above-mentioned lots. But the diagrams of the following three series of analyses add no explanation to the pattern other than that the periodicities of 40- and 20-basket widths pointed out in the above are far more strict and stronger ones than that impressed from the diagrams representing the results of the preceding series of analyses.

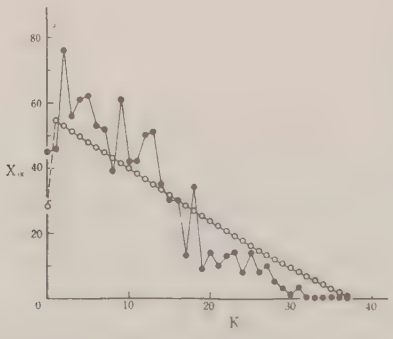



Fig. 13—A—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 6, Series Ⅰ : unit is 10 consecutive basket width = *ca.* 2 km).

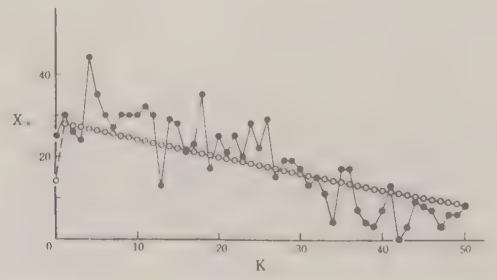



Fig. 13—A—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 6, Series Ⅱ : unit is 5 consecutive basket width = *ca.* 1 km).

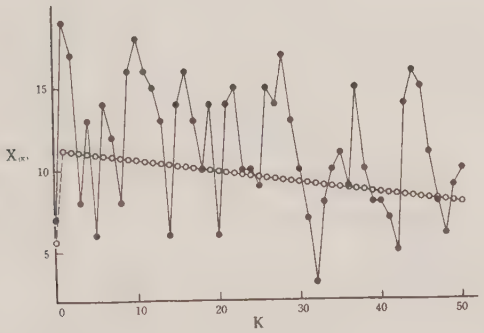



Fig. 13—A—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 6, Series Ⅲ : unit is 2 consecutive basket width= *ca.* 0.4 km).

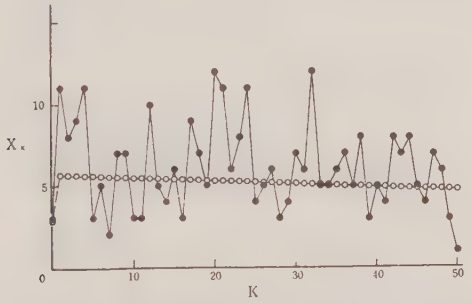



Fig. 13—A—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 6, Series Ⅳ : unit is 1 basket width=*ca.* 0.2 km).

Fig. 13—A—Ⅴ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 6, Series Ⅴ : unit is one hook-interval width=*ca.* 40 m).

*Albacore* : The presence of a large school covering the width as long as 200 baskets or thereabout and bearing the below-mentioned structure of the subordinate order is suggested from the general tendency of the deviations of the observed-values in Series I ; this school is thought to be located in the range from the 40th to the 240th basket or thereabout. And the short-periodic deviation of the observed-values causes the peaks observable at $k$ = 2, 5, 9, 13 and 18 lots; this means that the above-mentioned school contains from four schools of the subordinate order at minimum to at most six schools. And the presence of some individuals hooked out of the school is also suspected. The diagram of the following series may seem to allude to some facts, but I wish to give not so high significance upon them because each of the school of subordinate order mentioned above is estimated to be constituted of not so many hooked-individuals.

**Example 7**

*Yellow-fin tuna* : The diagram of Series I reveals that the population contains three schools, the centers of which are spaced by the width as long as 150 or 300 baskets one another (= *ca.* 30 km or 60 km), and Fig. 14 suggests that they are thought to

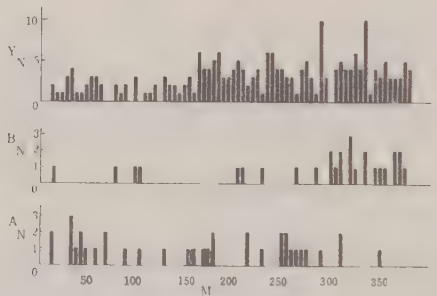



Fig. 14. Distribution of each species in each of five consecutive baskets in Example 7.

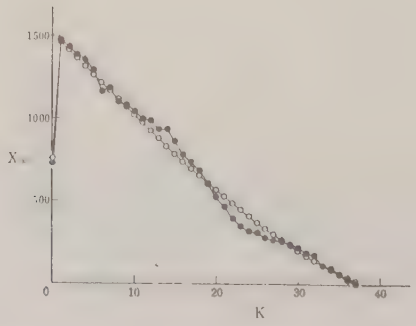



Fig. 15—Y—I. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 7, Series I : unit is 10 consecutive basket width = *ca.* 2 km).

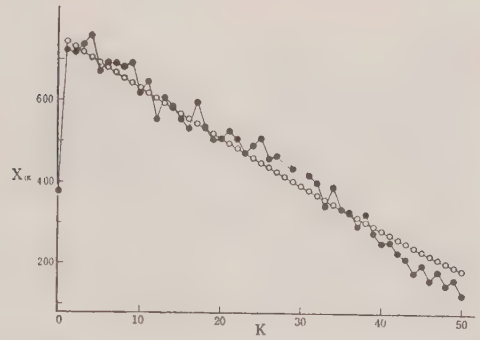



Fig. 15—Y—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 7, Series Ⅱ : unit is 5 consecutive basket width = *ca.* 1 km).

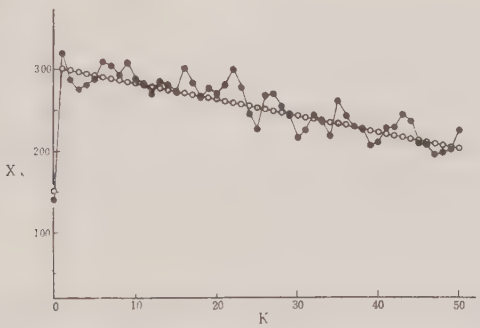



Fig. 15—Y—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 7, Series Ⅲ : unit is 2 consecutive basket width = *ca.* 0.4 km).

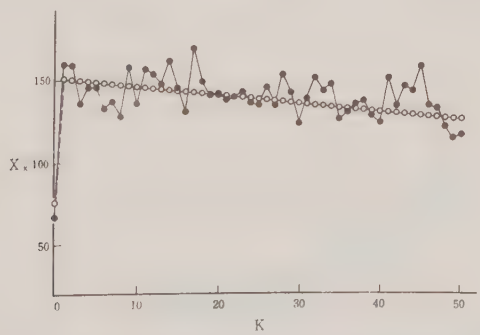



Fig. 15—Y—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 7, Series Ⅳ : unit is 1 basket width = *ca.* 0.2 km).

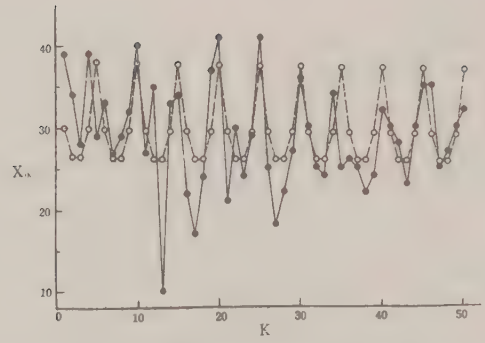



Fig. 15—Y—V. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 7, Series V : unit is one hook-interval width =*ca.* 40 m).

be located respectively at the positions around the 50th, the 200th and the 350th baskets; among these schools, the population size of the middle one is the largest of all. The structure of the subordinate order most clearly represented in the results of the following three series of analyses is that the heavily-occupied lots are observable spaced by the width as long as 15 baskets (= 3 km) or thereabout one another. And the width of the elemental cluster is estimated to be as long as or shorter than four hook-intervals, in which those each covering a space of one or four hook-intervals are more predominant than the others.

*Big-eye tuna* : The general tendency of the deviations of the observed-values in Series I shows the presence of two schools aggregated densely and each covering a wide range; the centers of these schools are spaced by the width about as long as 250 baskets (= 50 km) each other. From Fig. 14, it becomes clear that the schools illustrated in the above are located at the range from the first to the 100th basket and the range from the 200th to the hindmost basket, especially dense population is observable at the hindmost part of each school. And the diagram of Series I also

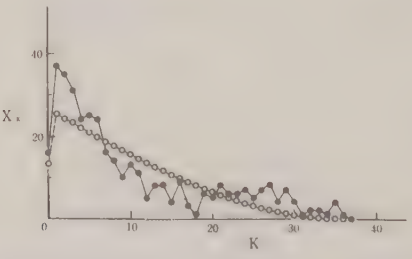



Fig. 15—B—I. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 7, Series I : unit is 10 consecutive basket width=*ca.* 2 km).

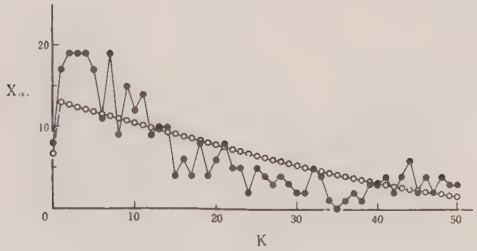



Fig. 15—B—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 7, Series Ⅱ : unit is 5 consecutive basket width $=ca.$ 1 km).

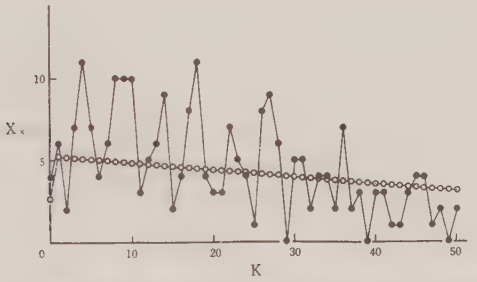



Fig. 15—B—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 7, Series Ⅲ : unit is 2 consecutive basket width $=$ $ca.$ 0.4 km).

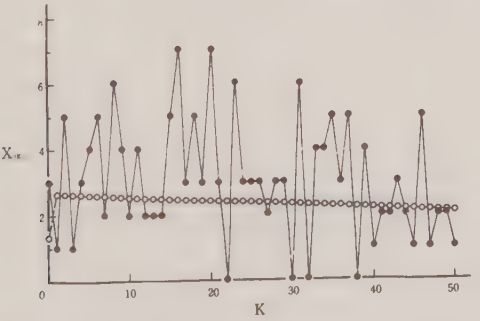



Fig. 15—B—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 7, Series Ⅳ : unit is 1 basket width $=ca.$ 0.2 km).

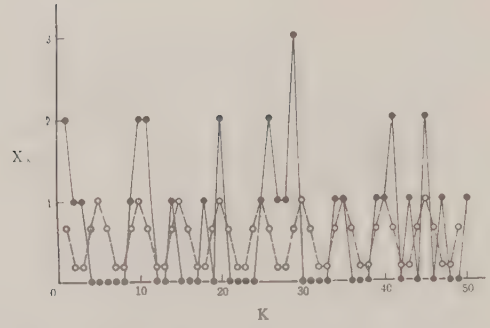



Fig. 15—B—V. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 7, Series V : unit is one hook-interval width= *ca.* 40 m).

suggests that these schools are constituted of each two schools of subordinate order, details of which are also easily assumable from Fig. 14. Then, some patterns may be deducible from the small deviations of the observed-values of this series and from the diagrams of the following series. But I wish to add no description, because each school of subordinate order mentioned above except that located at the range from the 260th to the hindmost basket is constituted of three hooked-individuals at maximum, consequently the deducible pattern is only that of the hindmost school of subordinate order, moreover not so high significance can be given to it.

*Albacore* : The deviation of the observed-values in the diagram of Series I shows rather clearly that there are two schools, the centers of which are spaced by the width as long as 200 baskets (= 40 km) each other, and at the middle of them, the presence of another not so distinct school is suspected. (Here, "not so distinct" indicates the school of not so strongly aggregated or constituted of fewer individuals). On Fig. 14, it is easily found out that two schools are located at the positions around the 50th and around the 250th baskets respectively and each of them is constituted of

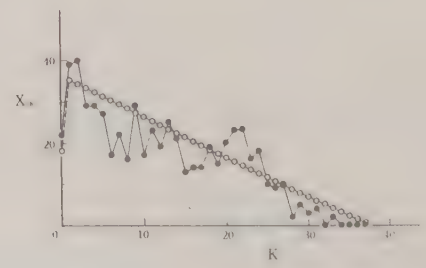



Fig. 15—A—I. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 7, Series I : unit is 10 consecutive basket width= *ca.* 2 km).

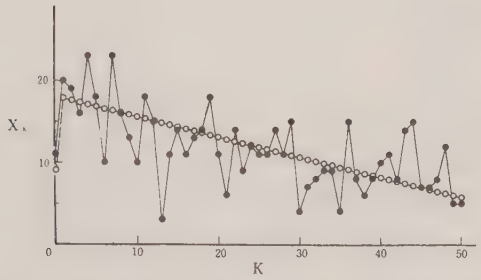



Fig. 15—A—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 7, Series Ⅱ : unit is 5 consecutive basket width=*ca.* 1 km).

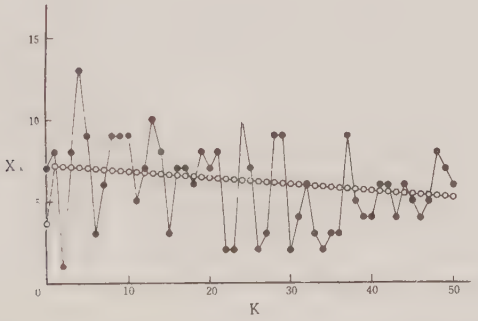



Fig. 15—A—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 7, Series Ⅲ : unit is 2 consecutive basket width=*ca.* 0.4 km).

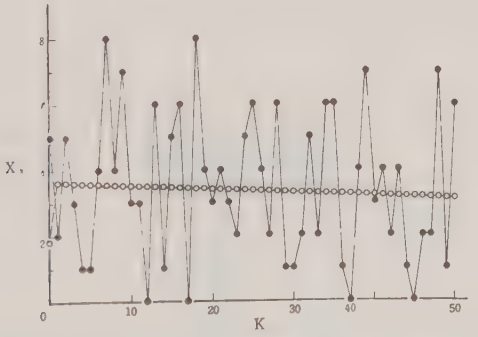



Fig. 15—A—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 7, Series Ⅳ : unit is 1 basket width=*ca.* 0.2 km).

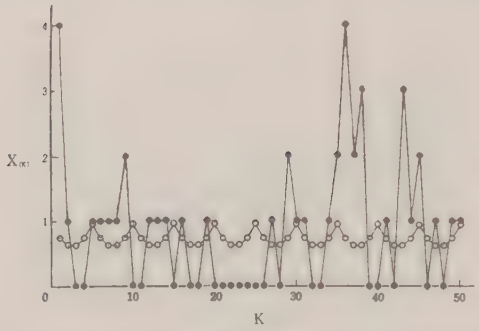



Fig. 15—A—Ⅴ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 7, Series Ⅴ : unit is one hook-interval width = *ca.* 40 m).

10 or more hooked-individuals, while not so distinct one is at the position around the 150th basket and this is constituted of six hooked-individuals or thereabout. The diagram of Series Ⅱ reveals that each school seems to be constituted of five subordinate clusters or thereabout, but significance of the pattern of this order is somewhat doubtful because, if so, each cluster results in being constituted of a single or two to at most five hooked-individuals. And for the same reason, no further structure is drawn out from the following series of analyses other than the fact that the pairs of individuals hooked adjoiningly or spaced by seven or nine baskets are frequently observable, although they are not so many as impressed from the word "frequently" but are only as many as four or a little more.

## Example 8

*Yellow-fin tuna* : On the diagram of Series Ⅰ, the presence of three schools, the centers of which are spaced by 6 or 13 lots (lot = 10 consecutive baskets and as long as 2 km) one another, is represented. And they may be located at the positions around the 20th, the 80th and the 150th baskets, respectively. The analysis of Series Ⅱ shows the same fact not so clearer than that of Series Ⅰ. The severe deviations

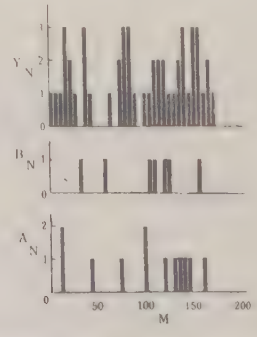



Fig. 16. Distribution of each species in each of five consecutive baskets in Example 8.

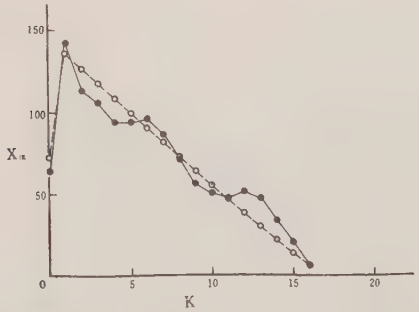



Fig. 17—Y—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 8, Series Ⅰ : unit is 10 consecutive basket width=*ca.* 2 km).

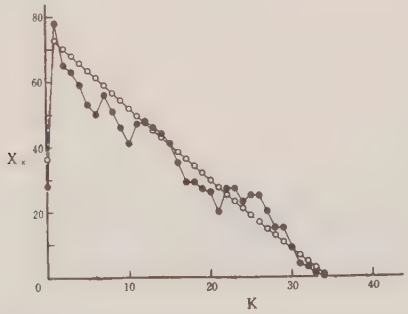



Fig. 17—Y—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 8, Series Ⅱ : unit is 5 consecutive basket width=*ca.* 1 km).

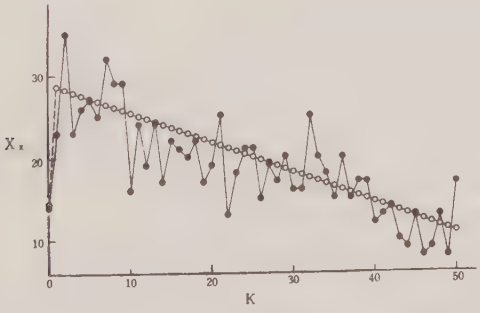



Fig. 17—Y—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 8, Series Ⅲ : unit is 2 consecutive basket width=*ca.* 0.4 km).

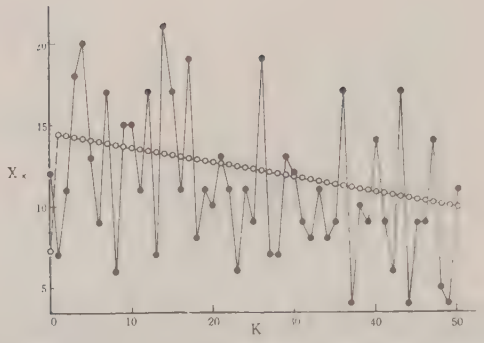



Fig. 17—Y—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 8, Series Ⅳ : unit is 1 basket width = *ca.* 0.2 km).

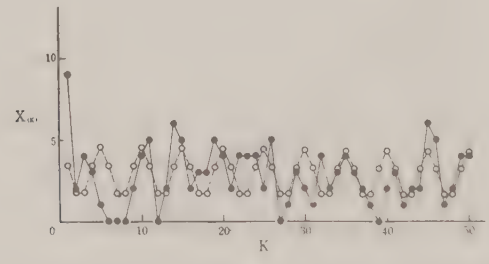



Fig. 17—Y—Ⅴ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 8, Series Ⅴ : unit is one hook-interval width = *ca.* 40 m).

of the observed-values in the diagrams of the following three series may seem to represent that there are some distinct structures of the subordinate orders. But it is probable that the above-mentioned structures of the subordinate orders actually indicate the distribution pattern of single individuals or clusters constituted of at most not so many individuals, because the hooked-individuals forming each school are not so many. Moreover, each peak is narrow; this means that the deviation is afraid to be strongly affected by the influence of accidental error. Therefore, I wish to give no interpretation of the further pattern deducible from the analyses of Series Ⅲ ~ Ⅴ because of being afraid of severe influence of accidental error. And only the diagrams are shown for reference' sake.

*Big-eye tuna* : The low observed-values and the estimated ones due to low occupied-rate emphasized by short length of a whole row of used gears make it impossible to analyze the pattern free from the influence of accidental error, although the pattern

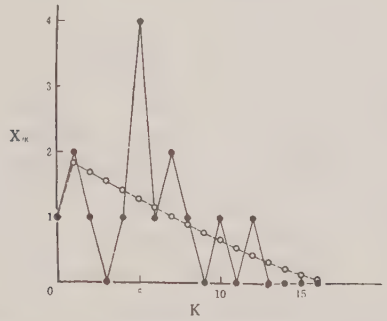



Fig. 17—B—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 8, Series Ⅰ : unit is 10 consecutive basket width= *ca.* 2 km).

coinciding considerably well with that assumable from Fig. 16 can be deduced from the diagram of Series Ⅰ.

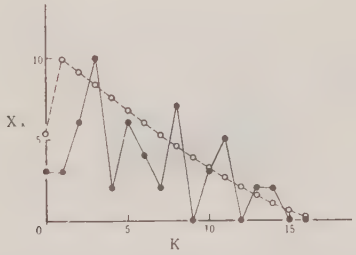



Fig. 17—A—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 8, Series Ⅰ : unit is 10 consecutive basket width=*ca.* 2 km).

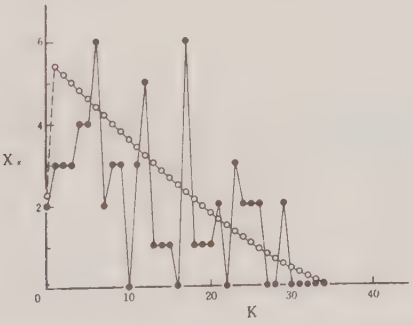



Fig. 17—A—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 8, Series Ⅱ : unit is 5 consecutive basket width= *ca.* 1 km).

*Albacore* : The deviation of the observed-values in the diagram of Series I clearly shows that six schools, which are located at the positions evenly spaced by a width as long as about 30 baskets each other, are contained in so evenly scattered population that only less individuals than that expected from chance distribution are hooked in the lots spaced by a width as long as or shorter than two lots including the same one from any occupied one, although most of the observed-values are not so high enough as to be deducible any fact excerted on no influence of accidental error. Here, I am afraid that it brings into confusion to make an image of the pattern from the above-mentioned description. But, it may become clearly recognizable when we consider the image of the pattern together with the fact that most of schools, in such an example of low occupied-rate as this and in which the hooked-individuals are distributed self-spacingly, are actually single occupied-lots occupied usually by not so many individuals. The positions and population sizes of respective schools are easily found out from Fig. 16. Because of the low observed-values, nothing is found out from the results of the succeeding series, although the figure showing the result of the next series may be somewhat obscurely suggesting the same pattern as that mentioned above.

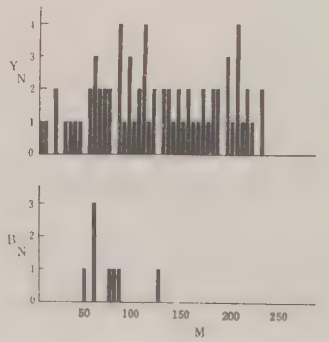



Fig. 18. Distribution of each species in each of five consecutive baskets in Example 9.

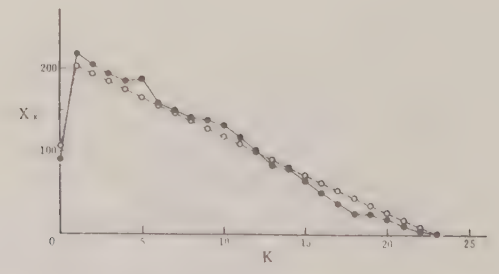



Fig. 19—Y—I. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 9, Series I : unit is 10 consecutive basket width = *ca.* 2 km).

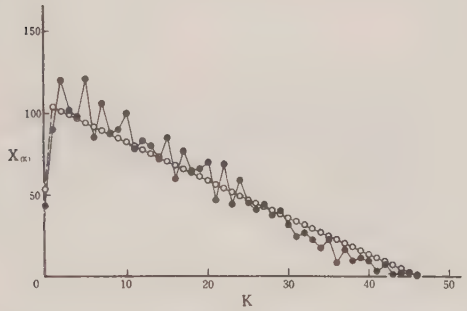



Fig. 19—Y—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 9, Series Ⅱ : unit is 5 consecutive basket width=*ca.* 1 km).

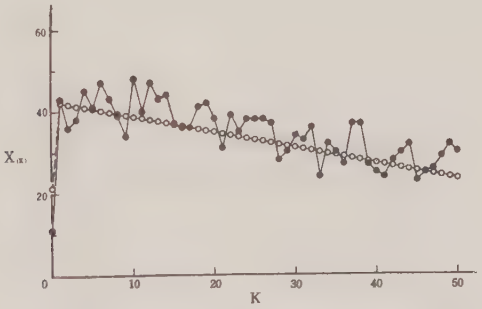



Fig. 19—Y—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 9, Series Ⅲ : unit is 2 consecutive basket width=*ca.* 0.4 km).

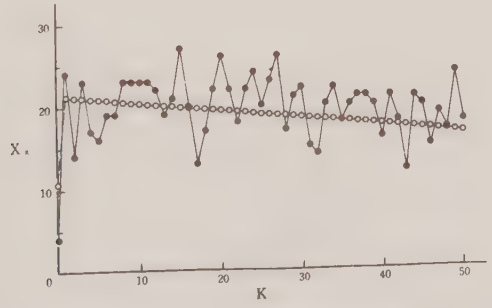



Fig. 19—Y—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 9, Series Ⅳ : unit is 1 basket width=*ca.* 0.2 km).

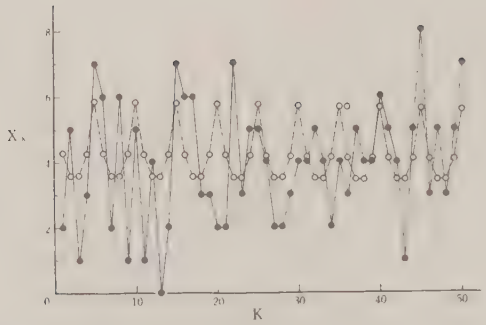



Fig. 19—Y—V. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 9, Series V : unit is one hook-interval width = *ca.* 40 m).

## Example 9

*Yellow-fin tuna* : The analysis of Series I reveals that the population contains a large school covering a space a little shorter than 150 baskets; this school may correspond to the part of higher occupied-rates from the 50th to the 200th basket, moreover this is rather clearly constituted of two schools of the subordinate order, the centers of which are spaced by a width as long as 100 baskets each other; and they are thought to be located at the ranges from the 50th to the 100th and around the 200th baskets. And the two-lot periodicity of the observed-values clearly observable in the diagram of Series II represents such further structure of subordinate order as every other lot is heavily occupied, as assumable from Fig. 18. The characteristics of the distribution pattern most clearly represented in the following two series of analyses are that the hooked-individuals are so evenly scattered that the number of individuals caught in the lots spaced by a width shorter than 10 baskets from any occupied-lot including the same one can not reach the values expected from chance

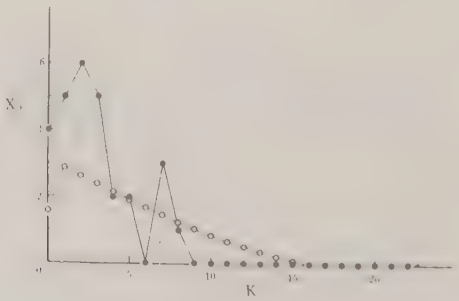



Fig. 19—B—I. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 9, Series I : unit is 10 consecutive basket width = *ca.* 2 km).

distribution, as noticeable from Fig. 18. The low observed-values make it impossible to deduce no further structure from the following series of analyses other than the fact that self-spacing pattern is assumable.

*Big-eye tuna* : Despite of the fact that total catch is not so good enough, it may well be said that the deviation of the observed-values in the analysis of Series I rather clearly shows the pattern coinciding well with that easily assumable from Fig. 18 —— *i.e.*, the population seems to contain two schools each aggregated clearly; their centers are spaced by an interval as long as 70 baskets or thereabout each other, although one of them is actually a single individual unfortunately hooked.

*Albacore* : Omitted, because no more than two individuals are hooked in a whole row of gears.

## Example 10

*Yellow-fin tuna* : The pattern most clearly suggested from the analysis of Series I is that the population contains two schools each covering the width as wide as or

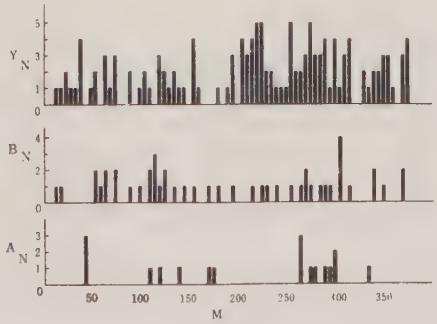



Fig. 20. Distribution of each species in each of five consecutive baskets in Example 10.

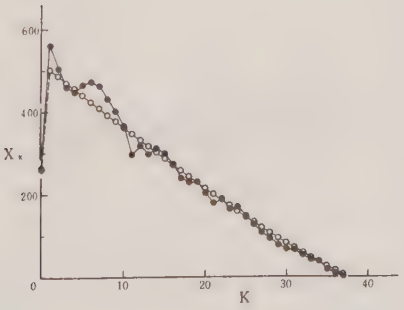



Fig. 21—Y—I. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 10, Series I : unit is 10 consecutive basket width=*ca.* 2 km).

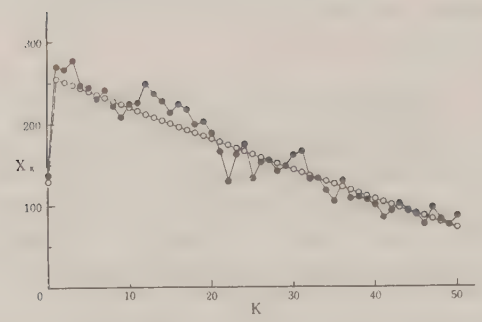



Fig. 21—Y—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 10, Series Ⅱ : unit is 5 consecutive basket width=*ca.* 1 km).

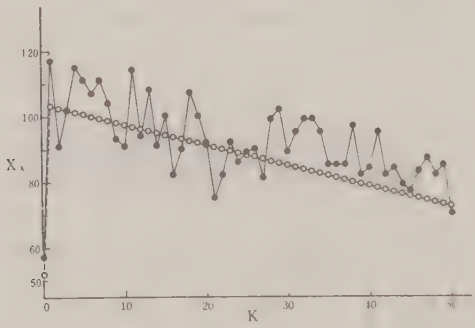



Fig. 21—Y—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 10, Series Ⅲ : unit is 2 consecutive basket width=*ca.* 0.4 km).

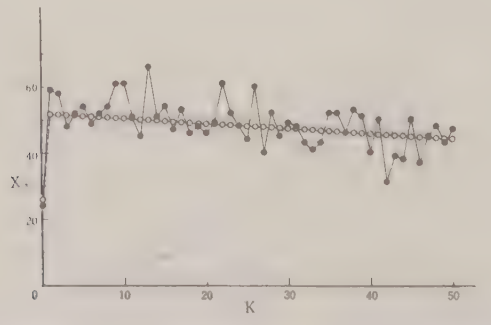



Fig. 21—Y—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 10, Series Ⅳ : unit is 1 basket width=*ca.* 0.2 km).

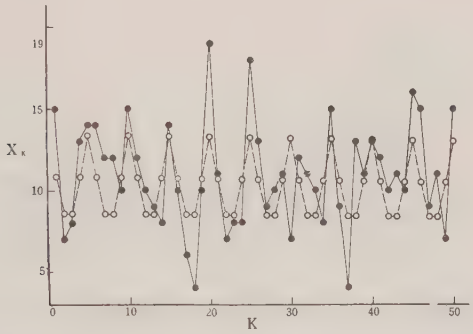



Fig. 21—Y—Ⅴ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 10, Series Ⅴ : unit is one hook-interval width=*ca.* 40 m).

wider than 30 baskets and their centers are spaced by an interval as long as or longer than 60 baskets, although hooked-individuals are scattered throughout a whole row of gears. Besides, the presence of another school is also suggested and this school is assumed to be spaced by a width a little longer than twice as long as the above-mentioned one. From Fig. 20, the schools represented clearly are thought to indicate the parts respectively around the 210th and the 270th baskets, and another is around the 345th basket. The analysis of Series Ⅲ shows almost the same fact, while the analysis of Series Ⅱ reveals that each of these schools is constituted of three clusters of the subordinate order or thereabout. And the analysis of Series Ⅳ represents the same fact less clearly. Adding the analysis of Series Ⅴ, we can find out the elemental structure widely influencing, sometimes reaching a width of $2\frac{1}{2}$ baskets, and this pattern is thought to be one of the most remarkable characteristics of the distribution pattern of this example.

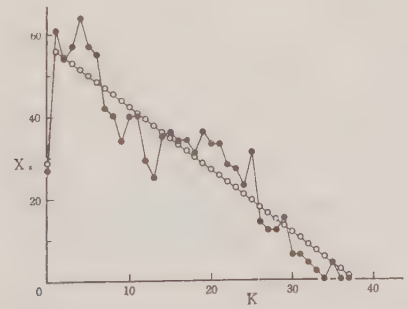



Fig. 21—B—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 10, Series Ⅰ : unit is 10 consecutive basket width=*ca.* 2 km).

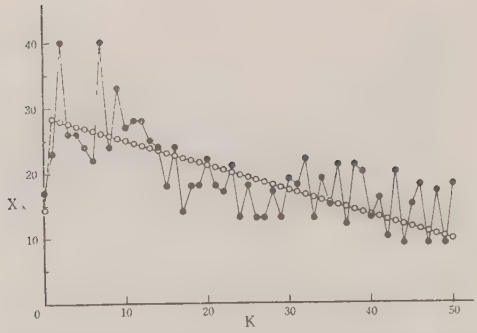



Fig. 21—B—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 10, Series Ⅱ : unit is 5 consecutive basket width = *ca.* 1 km).

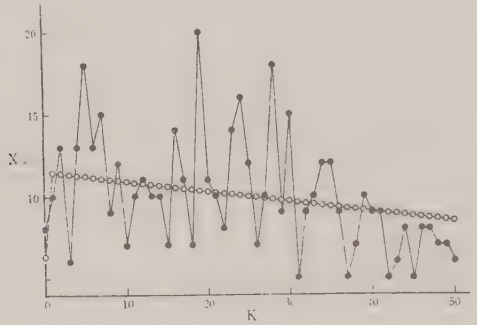



Fig. 21—B—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 10, Series Ⅲ : unit is 2 consecutive basket width = *ca.* 0.4 km).

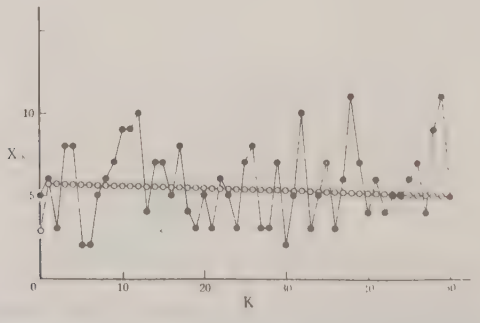



Fig. 21—B—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 10, Series Ⅳ : unit is 1 basket width = *ca.* 0.2 km).

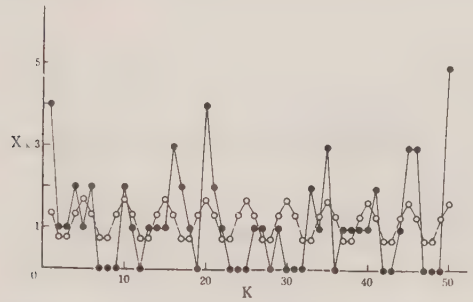



Fig. 21—B—V. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 10, Series V : unit is one hook-interval width= *ca.* 40 m).

*Big-eye tuna* : General tendency of the deviation of the observed-values in the diagram of Series I shows that the population seems to contain, generally speaking, two groups of schools, the centers of which are spaced by an interval as long as 200 baskets each other. And these groups of schools may be located at the ranges respectively from the 10th to the 125th basket and from the 230th to the hindmost basket. But this diagram examined more in detail, the peaks of the observed-values can be observed at $k = 4, 10, 15, 19, 25, 29$ and $35$ —— *i.e.*, almost regularly at each five lots; this shows that eight or less number of heavily-occupied lots, which may perhaps be the schools, are arranged spaced by a width as long as $5A$ lots ($A$ is a positive integer but not so large) one another. Accordingly, the groups of the individuals caught at about the 15th, the 65th, the 115th, the 270th, the 290th, the 305th, the 340th and the 370th baskets are thought to correspond to the schools mentioned above. The same facts may also be represented by the general tendencies of the deviations of the observed-values in the following series, although they are not so clear, owing to be influenced strongly by narrow but severe deviations indicating some structures of the subordinate orders.

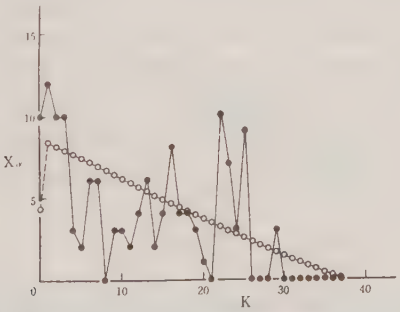



Fig. 21—A—I. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 10, Series I : unit is 10 consecutive basket width= *ca.* 2 km).

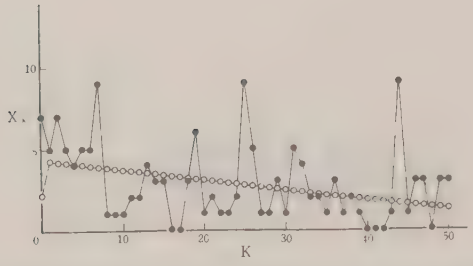



Fig. 21—A—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 10, Series Ⅱ : unit is 5 consecutive basket width= *ca.* 1 km).

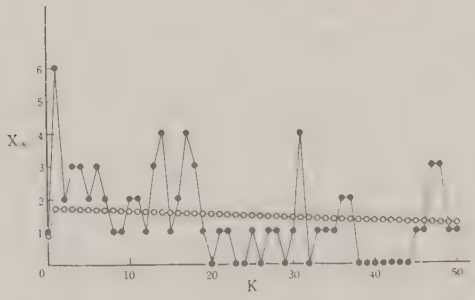



Fig. 21—A—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 10, Series Ⅲ : unit is 2 consecutive basket width= *ca.* 0.4 km).

*Albacore* : General tendency of the deviations of the observed-values in the diagram of Series Ⅰ shows that the population contains or is constituted of three schools, the centers of which are spaced by 15 and 25 lots (lot = 10 consecutive baskets) one another. From Fig. 20, it becomes clear that these schools may indicate single or groups of occupied-lots located about the 45th, the ranges from the 110th to the 175th basket and from the 265th to the 300th basket or including a single individual hooked at the 335th basket. And the short-periodic deviation shows the feature of the subordinate cluster-formation which is also easily recognizable from Fig. 20.

## Example 11

*Yellow-fin tuna* : The deviation of the observed-values in the analysis of Series Ⅰ reveals that the individuals are more frequently hooked in the parts near the both ends of a row of gears than regarded simply increasing with approach to the final end of hauling. This fact may seem to suggest that the sudden increase in occupied-

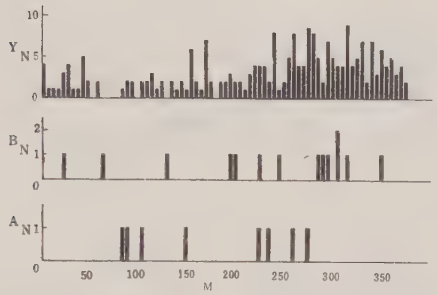



Fig. 22. Distribution of each species in each of five consecutive baskets in Example 11.

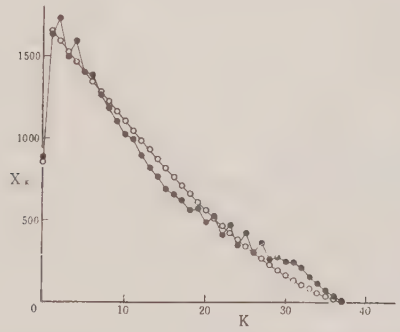



Fig. 23—Y—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 11, Series Ⅰ : unit is 10 consecutive basket width=*ca.* 2 km).

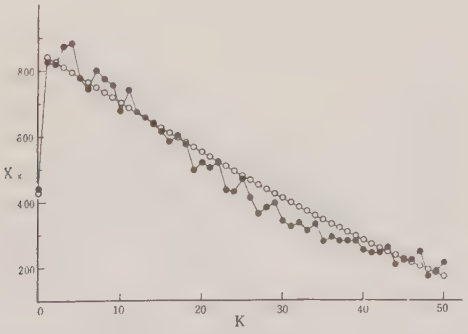



Fig. 23—Y—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 11, Series Ⅱ : unit is 5 consecutive basket width=*ca.* 1 km).

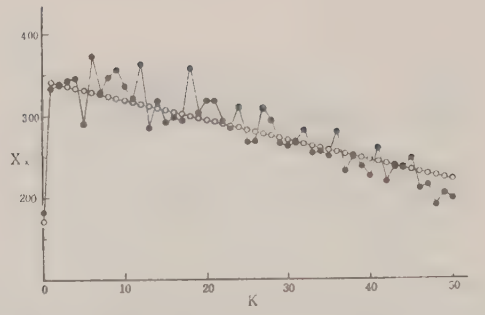



Fig. 23—Y—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 11, Series Ⅲ : unit is 2 consecutive basket width=*ca.* 0.4 km).

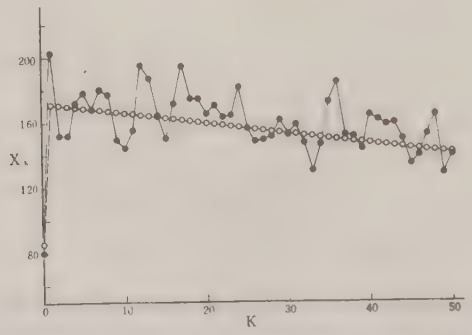



Fig. 23—Y—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 11, Series Ⅳ : unit is 1 basket width=*ca.* 0.2 km).

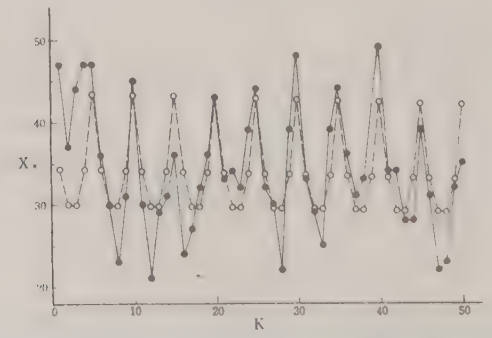



Fig. 23—Y—Ⅴ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 11, Series Ⅴ : unit is one hook-interval width=*ca.* 40 m).

rate in the parts latter than a certain basket is misregarded as if it is gradual one. But Fig. 22 shows that catch within the first 50 baskets is higher than those within the second (from the 51th to the 100th basket) and the third ones (from the 101th to the 150th basket). Therefore, it seems to be more probable to assume that two schools are hooked and their centers are spaced by a width as long as 300 baskets each other; and these schools may indicate the heavily-occupied parts respectively around the 25th and the 325th baskets. A little irregular periodicity of the observed-values of four-lot width in the diagram of Series Ⅱ shows that the schools of the subordinate orders are frequently observable spaced by a width as long as $20A$ baskets each other ($A$ is a positive integer but not so large). General tendency of the deviations of the observed-values in the following two series of analyses supports the presence of this pattern, while the short-periodic one adds such an information about the structures of the further subordinate orders as each subordinate school is spaced by a width as long as 20 or $20 \pm 5$ baskets from the adjoining ones or constituted of from single to all three schools of the subordinate orders arranged so as to be spaced by 15, 20 and 25 baskets from adjoining groups. And the analysis of Series Ⅴ shows that each elemental cluster covers a space as long as or shorter than a basket, especially one hook-interval.

*Big-eye tuna* : The low observed-values and the estimated ones due to poor total-catch do not allow me to give any significance upon the facts deducible from the diagrams. Therefore, I wish to describe nothing else than that many schools comparing with total catch are scattered throughout a whole row of gears; and this fact indicates that most of the schools are constituted of a single or not so many hooked-individuals.

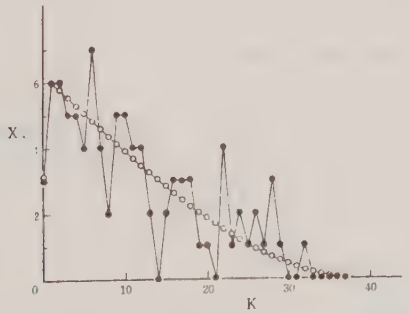



Fig. 23—B—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 11, Series Ⅰ : unit is 10 consecutive basket width $=ca.$ 2 km).

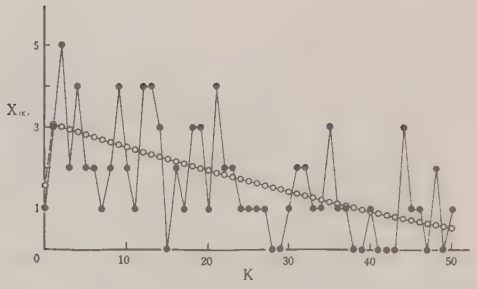



Fig. 23—B—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 11, Series Ⅱ : unit is 5 consecutive basket width =*ca.* 1 km).

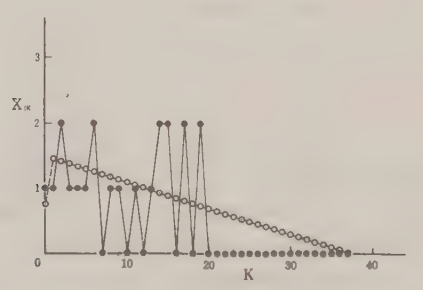



Fig. 23—A—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 11, Series Ⅰ : unit is 10 consecutive basket width= *ca.* 2 km).

*Albacore* : I could not obtain the high observed-values and the estimated ones enough to deduce any fact capable of giving any significance owing to scarcity of the hooked-individuals. And even if committing against the presumably severe influence of accidental error, I can barely deduce the fact that, as represented in Fig. 22, all individuals are scattered not all over the whole row but restricted within a space as long as a half of a row —— *i.e.*, forming a loosely linked school covering a space as long as a half of whole row.

## Example 12

*Yellow-fin tuna* : Slight gradient of counter direction to increase in soaking time is suggested from Fig. 24. Therefore, the influence of it is excluded from all series of the theoretical values, although whether it has to be excluded or not is doubtful. Usually, this spacing method is adopted for the purpose of finding out the probable number of schools contained and the distances among their centers as the most effective keys to decode the pattern. But we are already aware that, when the positions

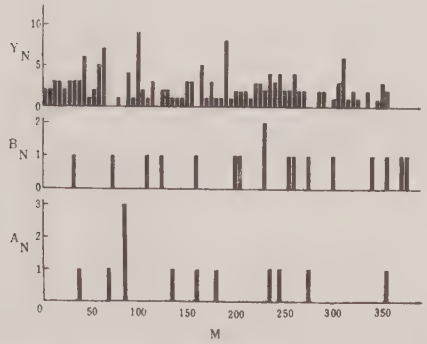



Fig. 24. Distribution of each species in each of five consecutive baskets in Example 12.

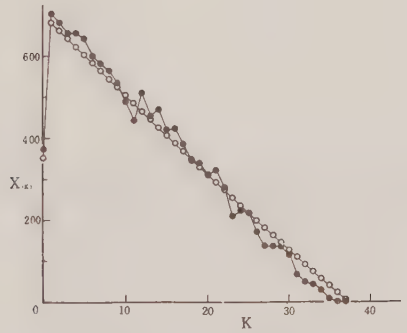



Fig. 25—Y—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 12, Series Ⅰ : unit is 10 consecutive basket width = *ca.* 2 km).

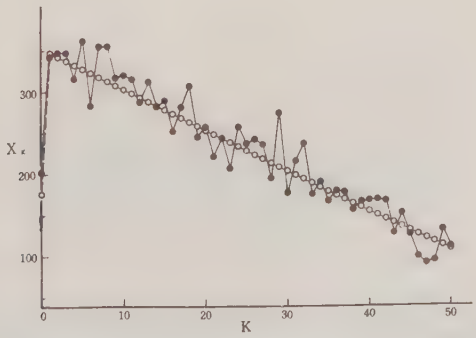



Fig. 25—Y—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 12, Series Ⅱ : unit is 5 consecutive basket width = *ca.* 1 km).

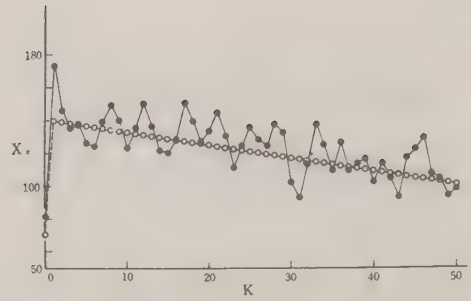



Fig. 25—Y—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 12, Series Ⅲ : unit is 2 consecutive basket width=*ca.* 0.4 km).

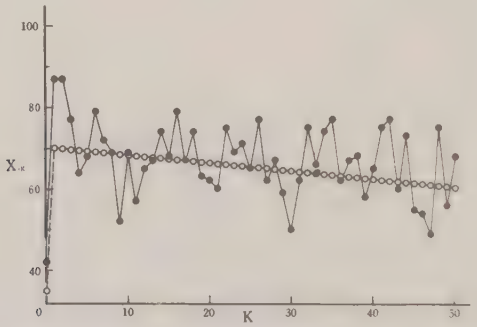



Fig. 25—Y—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 12, Series Ⅳ : unit is 1 basket width=*ca.* 0.2 km).

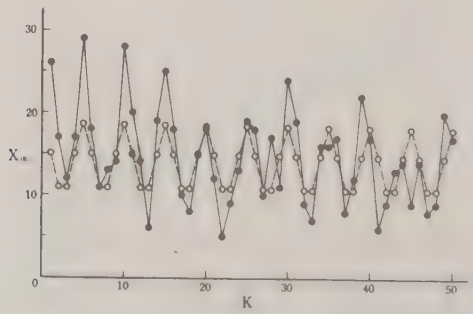



Fig. 25—Y—Ⅴ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Yellow-fin tuna, Example 12, Series Ⅴ : unit is one hook-interval width=*ca.* 40 m).

of some of schools are previously found out, the structures of the rests of them——consequently all structures——are decoded far easily. Fortunately this figure also strongly suggests the presence of schools hooked at the positions around the 60th, the 100th and the 185th baskets. Therefore, the diagrams showing the results of the spacing analyses considered together with the above-mentioned positions, the distribution pattern is analyzed. The peaks of the observed-values in the first series are found at $k = 4, 12, 14, 16, 21, 25$ and 29 lots (lot = 10 consecutive baskets). And the positions spaced by these key-lengths from the above-mentioned positions are the 220th, the 310th and the 350th baskets. Therefore, examining the corresponding parts in Fig. 24, Table 22 and the original records, I found that these parts were heavily occupied and able to be regarded as the positions of schools. Thus, the positions of six schools are estimated, and it is self-evident that all intervals among these schools do not take any value other than the above-mentioned key-lengths; but before ending the discussion of the pattern of this step, it is necessary to examine whether or not there is any key-length which does not occur among the intervals of these schools. And if there is any key-length showing the value other than the intervals among these schools, the schools causing the occurrence in such a key-length should be seaked about. But actually there is no such a key-length, accordingly no school else than the above-mentioned ones is thought to be contained. And the results of the following three series of analyses examined, the $6 \sim 8$ basket periodicity of heavily-occupied baskets is found out ; and this periodicity is expressed in a little regular one of four-lot width in Series Ⅲ and the general tendency of the deviations of the observed-values in the diagram of Series Ⅳ. And also the last two series show that far more individuals than expected from chance distribution are hooked in the baskets spaced by a width shorter than three baskets from any occupied one. And the same pattern is also clearly represented in the analysis of Series Ⅴ as one of the characteristics of the distribution pattern of this example.

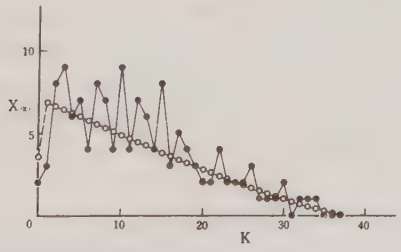



Fig. 25—B—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 12, Series Ⅰ : unit is 10 consecutive basket width = *ca.* 2 km).

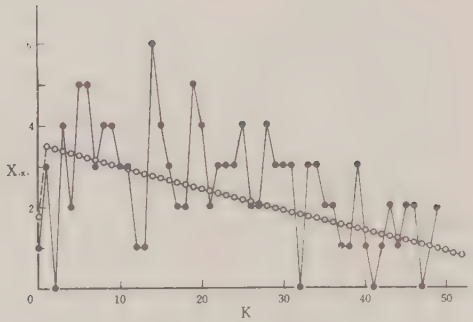



Fig. 25—B—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 12, Series Ⅱ : unit is 5 consecutive basket width $=ca.$ 1 km).

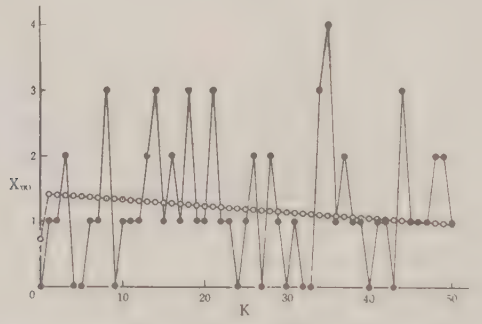



Fig. 25—B—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Big-eye tuna, Example 12, Series Ⅲ : unit is 2 consecutive basket width $=ca.$ 0.4 km).

*Big-eye tuna* : The following facts may be said, although both the observed-values and the estimated ones, especially those in the range $k>15$, are not so large enough that they enable to deduce any fact: the individuals are hooked so self-spacingly that only less individuals than in the chance distribution are caught in respective occupied-lots and the lots adjoining to them. And the number of the schools contained is estimated to be from six at minimum to 12 at maximum, because the peaks of the observed-values are located at $k=3$, 5, 7, 10, 12, 15, 17, 22, 26, 30 and 33. But, against the fact that the observed-values at $k=17$, 22 and 33 are not so largely exceeding the estimated ones, sums of two other $k$ rather frequently take these values, and the same fact can be said to the observed-value at $k=15$ where it exceeds largely the estimated one. Accordingly, it may be more probable to consider that the maximum number of schools is 9. But I do not wish to give any significance upon these facts, and wish to consider that all individuals are hooked self-spacingly throughout a whole

row of gears, because in any case, respective schools detected above indicate frequently a single or a pair of hooked-individuals and rarely three individuals at maximum.

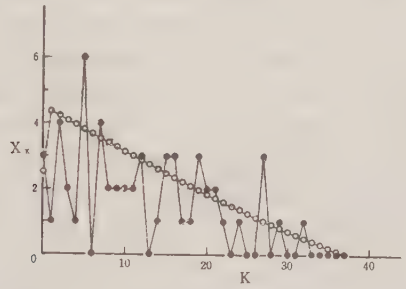



Fig. 25—A—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 12, Series Ⅰ : unit is 10 consecutive basket width =*ca.* 2 km).

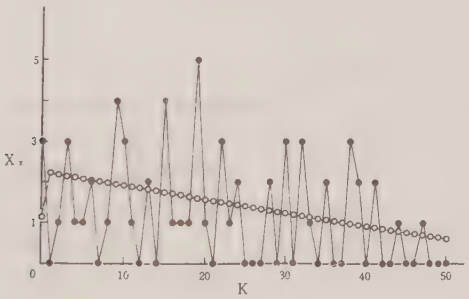



Fig. 25—A—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of the same species, in contrast with that of the theoretically estimated ones (Albacore, Example 12, Series Ⅱ : unit is 5 consecutive basket width= *ca.* 1 km).

*Albacore* : Enough individuals capable of obtaining the results of analyses suffering from no influence of accidental error can not be hooked. Therefore, from the diagram showing the results of analyses, nothing can be drawn out else than that the individuals are scattered self-spacingly all over a whole row of gears.

## 2. Summarized results of the spacing analysis on the distribution patterns of three species of tuna

*Yellow-fin tuna* : Relatively many individuals of the yellow-fin tuna are caught by a row of gears in each operation. Accordingly, high significance can be given to the patterns deduced from the results of the analyses, even including those at the ele-

mental step. And the patterns described in the exposition of particular example are summarized as follows:

1) No example showing clearly self-spacing pattern can be found out.

2) All examples show the patterns of several-fold contagiousness, although the contagious degree at each step is very weak, moreover influencing-widths of the schools of the highest order vary severely example by example —— the width from a few consecutive baskets to longer than a half of a whole row of gears.

3) There are some examples in which from one school to at most less than five schools of weak contagiousness each covering widely are contained. Further it is also discerned that most of these schools are constituted of many schools of subordinate orders, the width of each of which is 10 consecutive basket order; while other examples lack the structure covering widely and seem to be constituted of many schools of the same magnitude as the subordinate schools of the above-mentioned examples. But no fact having clear relation to the fact whether a certain example lacks the structure covering widely or not can be found out yet.

4) It is suspected that, when an example contains not so many schools, the centers of the schools occur a little frequently in the first and the hindmost two lots of 50 consecutive baskets, although this is not so strict.

*Big-eye tuna* : Generally speaking, the hooked density of the big-eye tuna in each operation does not reach a value as high as an individual per 10 consecutive baskets. Accordingly, I can not give so high significance upon the structures deduced from the results of the above-mentioned analyses. And if the results of the analyses may suggest the presence of many schools in a certain example, the population sizes of respective schools become extremely small and the structure within a short interval, which is expected to show the pattern specific to respective species and has much interests, can not be found out without unnegligible influence of accidental error due to the scarcity of hooked-individuals forming respective schools. But the following descriptions of the general tendency are given for reference' sake, although significance of some of them is doubtful.

1) Among 12 examples, Examples 8 and 9 are omitted, because total numbers of used gears are not so many enough.

2) Relatively clear school-formation can be admitted in Examples 1, 2 and 4, although population sizes of respective schools are not so large and each of them is occasionally constituted of one or few hooked-individuals. And the similar but not so clear structure is found out in Example 7.

3) A self-spacing pattern of the hooked-individuals is observable in Examples 3, 5 and 12. And the similar pattern is also suggested in Example 11 but at the same time this example alludes to slight school-formation to consider the structure as a whole.

4) The examples, which are constituted of relatively many individuals —— Examples 6 and 10 —— represent such a structure as they contain each two groups of schools although it is not so strict, and 20- and 40-basket periodicities of heavily-occupied baskets are alluded to in the former example while the latter example shows not so

clear 50- basket periodicity as the structure of the subordinate order.
5 ) But no factor having clear relation to these differences in the types of the distribution pattern is found out yet.

*Albacore* : Like the big-eye tuna, the scarcity of the hooked-individuals in each operation makes it impossible to give high significance upon the facts deduced from the results of the analyses. And also no description of the distribution pattern within a short range can be given. But the following general tendencies are described for reference' sake, although significance of some of them is somewhat doubtful.
1 ) Examples 1 and 9 are left aside the consideration, because of the extreme scarcity of the hooked-individuals. And Example 8 is also omitted because the total number of used gears is not so many.
2 ) As clearly represented in Examples 3, 5 and 6 and obscurely in Example 11, it seems to be one of the characteristics of the distribution pattern of this species that most of the hooked-individuals intend to form a single school covering widely in which the individuals are rather self-spacingly distributed.
3 ) But there are some examples in which the hooked-individuals are inclined to form many schools (clearly in Examples 2 and 10 while obscurely in Examples 4 and 7 ).
4 ) Otherwise, self-spacing pattern can be observed (in Example 12), which is thought to be one of the modified types of the distribution pattern classified into column 2 (whole of gears is entirely covered by a wide school) or in column 3 (not so large population is splited into too many schools scattered throughout a row, consequently each school is constituted of extremely small population).
5 ) No factor having clear relation to these differences in the types of the distribution pattern can be found out.

## Results of the Correlation Analysis

The distribution patterns within the individuals of the same species were analyzed in detail in the preceding paragraph and in the preceding report. But among three species of tuna of commercial importance, the yellow-fin tuna and the big-eye tuna take the similar body size and rather common foods (roughly speaking piscivora), while only the albacore is rather plankton-feeder and its body size is a little smaller than the former two. Accordingly, the yellow-fin tuna and the big-eye tuna are probable to take the similar habitat or to form common schools when they are considered with large scale, and also probable to segregate their habitat each other when they are examined in detail, as suggested and certified to terrestorial animals. On the other hand, the hooked-population sizes of the yellow-fin tuna in these examples are large, in contrast with the fact that those of the big-eye tuna and the albacore are small. And it is one of the frequently observable characteristics of the social habits of fishes that, when population size or density of each species is not so high, fishes are inclined to form the common schools overcoming some differences in species moreover

their food habits, swimming abilities, *etc.* Therefore, the big-eye tuna and the albacore are probable to form the common schools against the differences in their food habits and in body sizes. And it is of interest and of importance to know the social relation observable among the individuals of the different species——whether they are inclined to take common habitats (conveniently, called forming the common schools), to be distributed independently or repulsively of each other, because of not only the above-mentioned reasons but also from many other bio-sociological interests; this relation is represented, in the projected distribution-pattern along long-line, as that among the hooked-positions of the different species. And it is presupposable that this relation considered a row of gears as a whole can be easily assumable from the distribution patterns of respective species which are described in the above as the preliminary step; while the relation of the hooked-positions within a short range is hardly assumable from the distribution patterns of respective species, against the fact that it is thought to have more interests. Accordingly, at first, the expectant outline of the correlation to consider a row as a whole is forecasted from the distribution patterns of respective species; next, the differences in the actually obtained ones adopting the analysis method of correlation mentioned above from the forecasted ones are examined and then the reasons causing them are discussed in case by case although such differences are not so frequently observed. But, for the correlation observable within a short range, any description can hardly be given to it, despite of its importance and deep interests, because the hooked-population sizes of each one or both of the two species are not so large enough as to be deducible any pattern of significance, although predominance of the hooked-population size of a species superficially raises the observed-values and the estimated ones into the magnitude falsely large enough capable of giving some significance.

The unit-lengths of respective series-numbers of correlation analyses are the same as those of the spacing analyses. The solid circles in the diagrams showing the results of the correlation analyses show the observed-values; while the open ones are the theoretical-values estimated from Formulae (8) and (9) (for Series Ⅰ～Ⅵ) or Formulae (10)～(14) (for Series Ⅴ). And because of the same reason as that in the spacing analyses, some series are omitted based on the same criteria as those in the spacing analyses, in which the words "the catch of less abundant species" are substituted for the word "the catch".

## 1. Exposition of particular example

### Example 1

No consideration can be given to the relation between the albacore and any other species, because no more than two individuals of the albacore are hooked.

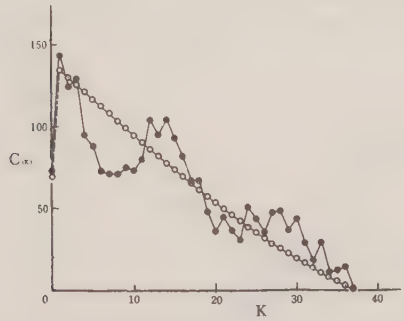



Fig. 26—Y B—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 1, Series Ⅰ : unit is 10 consecutive basket width= *ca.* 2 km).

Notes (common to Figs. 26～37) :

Solid circles show the observed values; while open ones indicate the estimated ones.

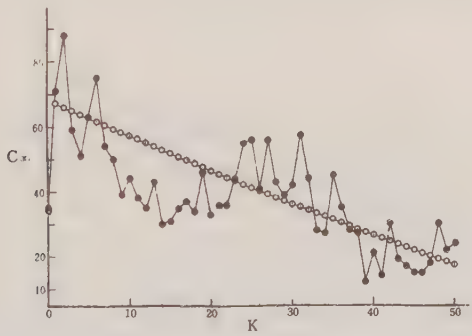



Fig. 26—Y B—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 1, Series Ⅱ : unit is 5 consecutive basket width= *ca.* 1 km).

*Yellow-fin tuna—Big-eye tuna* : The diagram showing the results of the spacing analysis of the yellow-fin tuna suggests that most of the hooked-individuals form three schools located at the positions around the 80th, the 200th and the 350th baskets and two obscure ones located at the positions around the 140th and the 300th baskets; while that of the big-eye tuna tells us that population is constituted of two schools located at the positions arouud the 200th and the 350th baskets to which a single individual hooked at the first lot is attached. Thus all individuals of the big-eye tuna, except an individual, are hooked in the common parts occupied by the schools of the yellow-fin tuna. Therefore, aggregative tendency must be a little clearly suspected in the correlation-diagram. But it is also expected that this tendency will be not so clear because no individual of the big-eye tuna is hooked in the parts where the other distinct school of the yellow-fin tuna and two obscure ones are hooked. And the

actually obtained correlation-diagram takes the features coinciding well with the pattern forecasted from the above-mentioned preliminary consideration.

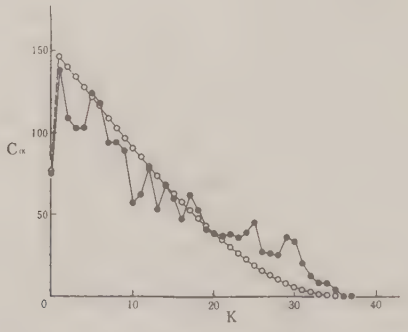



Fig. 27—Y B—I. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 2, Series I : unit is 10 consecutive basket width = *ca.* 2 km).

## Example 2

*Yellow-fin tuna—Big-eye tuna* : The diagrams of the first series of the spacing analysis of both the yellow-fin tuna and the big-eye tuna show essentially the same patterns, which indicate that there are a school or isolated single-individual hooked at the position around the 50th basket and a group of schools, the center of which is spaced by a width as long as 250 baskets (= 50 km) or thereabout from the above-mentioned one. Accordingly, the tendency to form the common school or to occupy the common habitat should be suspected in the correlation-diagram. But the group of the yellow-fin tuna schools is clearly constituted of two schools spaced by a width as long as 50 baskets (= 10 km) each other. Therefore, another group of high observed-values in the correlation-diagram is expected to be observable at $k = 5$ or thereabout (unit = 10 consecutive baskets); this indicates the positional relation within the group of schools; besides, other groups of high observed-values are also expected to be observable around $k$ = a little longer than 25 (unit = 10 consecutive baskets); they indicate the relation of positions of schools located at the position around the 50th basket between the groups of schools of each other's species located at the position around the 300th basket. But the general tendency of the observed-values in the correlation-diagram obtained actually shows the features coinciding well with the results of the preliminary consideration, except for the fact that the observed-values around $k = 0$ and 5 (unit = 10 consecutive baskets) exceed the adjoining ones but do not reach the theoretical-values. And this is thought to be, at least partly, due to the distribution pattern of the individuals of the yellow-fin tuna constituting the group of schools.

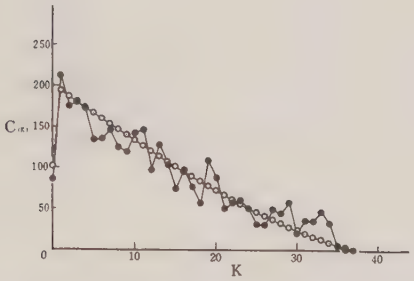



Fig. 27—Y A—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 2, Series Ⅰ : unit is 10 consecutive basket width = *ca.* 2 km).

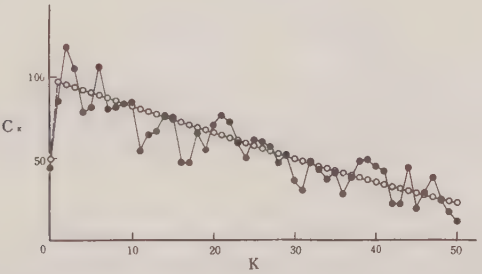



Fig. 27—Y A—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 2, Series Ⅱ : unit is 5 consecutive basket width = *ca.* 1 km).

*Yellow-fin tuna—Albacore* : The hooked-population of the albacore is constituted of three individuals aggregated at the position around the 20th basket and of a scattered school covering a space from the 170th to the 350th basket. Therefore, both species are superficially thought to be hooked in the same or the adjoining parts in a row. But the tendency of the deviations showing the aggregative relation is expected to be not so clear, because the albacore forms extremely scattered school; moreover, even if obtained, not so high significance can be given to it, because of the scarcity of the hooked-individuals of the albacore. And the observed-values in the correlation-diagram are expected to be strongly reflecting the relation of the positions of schools of the yellow-fin tuna between those of the individuals of the albacore, but not so clear relation can be expected because of many positions of respective species. Therefore, it is highly probable that the deviation of the observed-values in the correlation diagram reflects the relation of the positions of three individuals of the albacore aggregated densely and hooked at the position around the 20th basket between

the positions of the schools of the yellow-fin tuna. The occurrence of most peaks of the observed-values in the correlation-diagram obtained actually can be explained from the above-mentioned reasons. But there are some other peaks observable at $k = 1$, 16 and 23, the occurrence of which is unable to be explained from the above-mentioned reasons and they are thought to reflect the relation of the positions of schools or individuals of the yellow-fin tuna and the individuals of the albacore forming a scattered school.

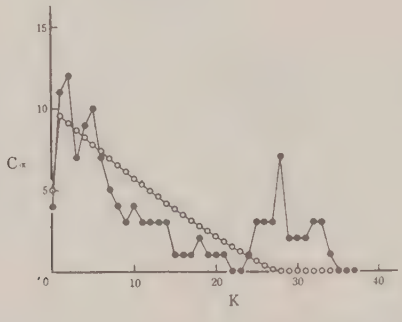



Fig. 27—B A—I. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of big-eye tuna and albacore, in contrast with that of the theoretically estimated ones (Example 2, Series I : unit is 10 consecutive basket width = *ca.* 2 km).

*Big-eye tuna—Albacore* : Two schools of the big-eye tuna are hooked in the same parts covered by a scattered school of the albacore, especially overlapping the heavily-occupied parts and the centers of these big-eye tuna schools are spaced by a width as long as 50 baskets (= 10 km) each other. Besides, a single isolated-individual of the big-eye tuna is hooked in the basket not so apart from another school of the albacore constituted of three hooked-individuals aggregated densely. Accordingly, the observed-values in the correlation-diagram in the range from $k = 0$ to 2 or 3 and around 5 (unit = 10 consecutive baskets) are easily expected to exceed the theoretical-values; this means that the individuals of both species are inclined to form the common schools or to take the common habitat. Besides, an albacore school located at the position around the 20th basket is spaced by a little longer width than 300 baskets (= 60 km) from two schools of the big-eye tuna, while a single individual of the big-eye tuna hooked at the position around the 50th basket is spaced by a width a little shorter than 300 baskets (= 60 km) from another school of the albacore constituted of scattered individuals. Therefore, high observed-values in the correlation-diagram are expected to be observable around $k = 30$. Taking these results of preliminary consideration, I examined the actually obtained correlation-diagram, but no fact else than that expected preliminarily could be found out.

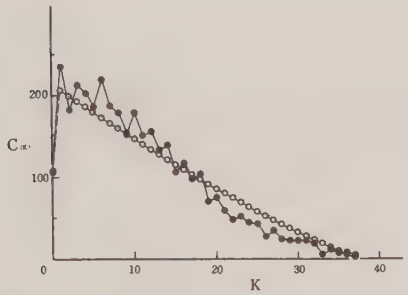



Fig. 28—Y B—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 3, Series Ⅰ : unit is 10 consecutive basket width= *ca.* 2 km).

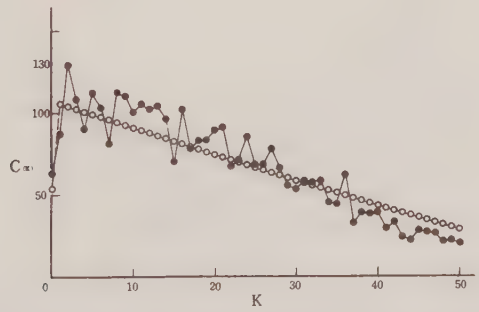



Fig. 28—Y B—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 3, Series Ⅱ : unit is 5 consecutive basket width= *ca.* 1 km).

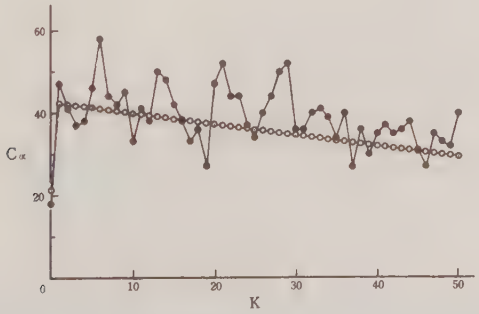



Fig. 28—Y B—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 3, Series Ⅲ : unit is 2 consecutive basket width= *ca.* 0.4 km).

### Example 3

*Yellow-fin tuna—Big-eye tuna* : The yellow-fin tuna constitutes a single wide-school covering a space from the 140th to the 315th basket. But the individuals of the big-eye tuna seem to scatter rather self-spacingly throughout a row. Accordingly, the correlation-diagram is expected to show the similar feature to the spacing-diagram of the yellow-fin tuna, *i.e.*, the correlation-diagram is expected to indicate that the pairs of the individuals, one of which is the individual of the yellow-fin tuna and the other is the big-eye tuna spaced by a width from 0 to as long as the width of the yellow-fin tuna school [315 − 140 = 175 baskets (= 35 km)], are more frequently observable than expected from independent distribution. And the actually obtained correlation-diagram takes the features coinciding quite with the pattern assumed theoretically.

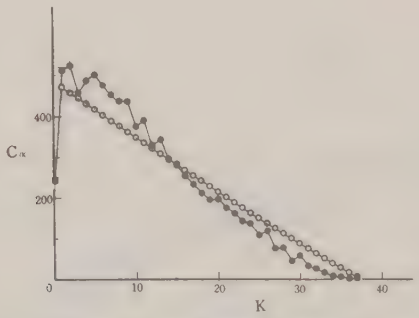



Fig. 28—Y A—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 3, Series Ⅰ : unit is 10 consecutive basket width = *ca.* 2 km).

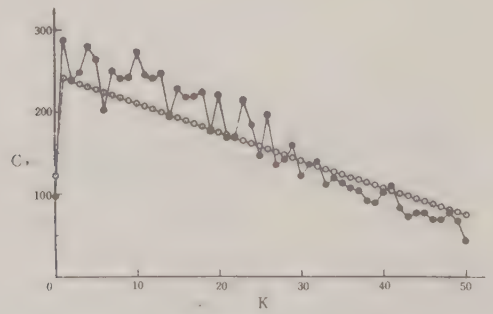



Fig. 28—Y A—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 3, Series Ⅱ : unit is 5 consecutive basket width = *ca.* 1 km).

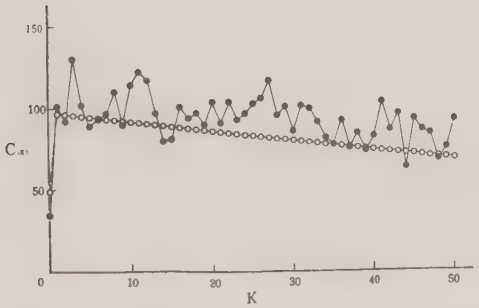



Fig. 28—Y A—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 3, Series Ⅲ : unit is 2 consecutive basket width= *ca.* 0.4 km).

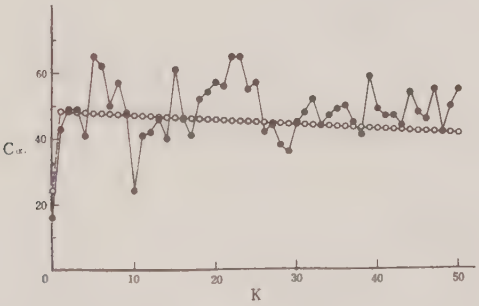



Fig. 28—Y A—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 3, Series Ⅳ : unit is 1 basket width=*ca.* 0.2 km).

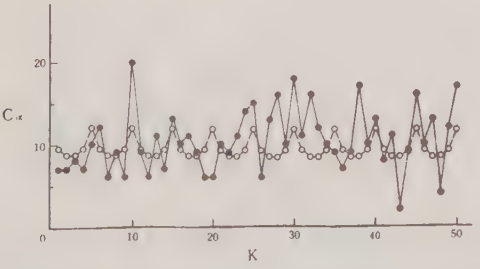



Fig. 28—Y A—Ⅴ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 3, Series Ⅴ : unit is one hook-interval width=*ca.* 40 m).

*Yellow-fin tuna—Albacore* : The hooked-individuals of the albacore also form a single school scattered widely. Therefore, the observed-values in the correlation-diagram in the range corresponding to the width of the overlapping part of the schools of both species are expected to exceed the theoretical-values continuously and distinctly, while those of the rests of them decrease at first gradually then sharply with increase in $k$ and take the values lower than the theoretical ones. And the actually obtained correlation-diagram does not show any other pattern than that assumed, except for the fact that less individuals of each species than expected are hooked by the hooks spaced by the width shorter than a basket (= 0.2 km) from any hook occupied by the individual of other species.

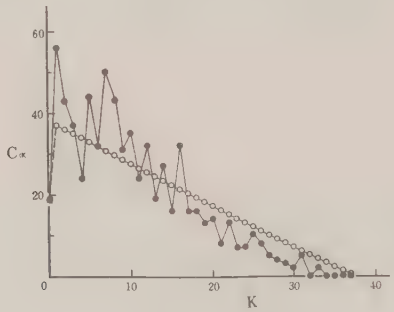



Fig. 28—B A—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of big-eye tuna and albacore, in contrast with that of the theoretically estimated ones (Example 3, Series Ⅰ : unit is 10 consecutive basket width = *ca.* 2 km).

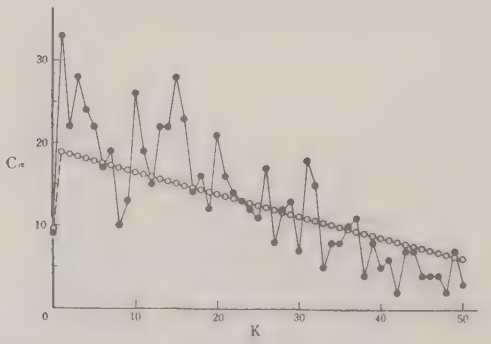



Fig. 28—B A—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of big-eye tuna and albacore, in contrast with that of the theoretically estimated ones (Example 3, Series Ⅱ : unit is 5 consecutive basket width = *ca.* 1 km).

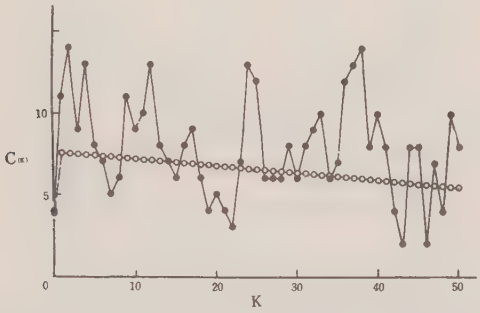



Fig. 28—B A—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of big-eye tuna and albacore, in contrast with that of the theoretically estimated ones (Example 3, Series Ⅲ : unit is 2 consecutive basket width = *ca.* 0.4 km).

*Big-eye tuna—Albacore* : As mentioned above, the hooked-individuals of the albacore, to see generally, form a single school, against the fact that the hooked-individuals of the big-eye tuna are scattered self-spacingly. Therefore, the correlation-diagram is preliminarily expected to show the similar pattern to that between the yellow-fin tuna and the big-eye tuna of this example. And the actually obtained correlation-diagram shows that both species have no special relation except those easily assumable from the distribution patterns of both species.

## Example 4

*Yellow-fin tuna—Big-eye tuna* : The hooked-individuals of the yellow-fin tuna are scattered throughout a whole row of gears, in which heavily-occupied lots are distributed showing a little irregular four-lot periodicity. But the hooked-individuals of the big-eye tuna clearly form five schools, although the population sizes of the schools

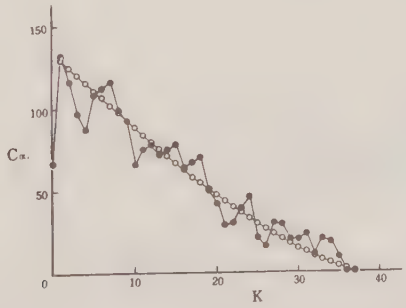



Fig. 29—Y B—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 4, Series Ⅰ : unit is 10 consecutive basket width = *ca.* 2 km).

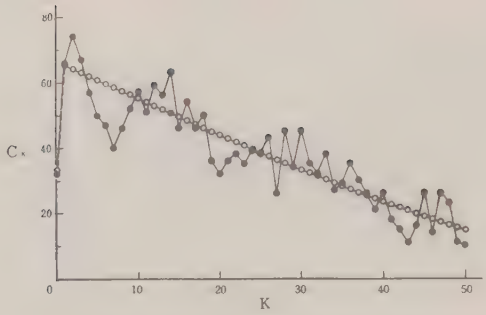



Fig. 29—Y B—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 4, Series Ⅱ : unit is 5 consecutive basket width = *ca.* 1 km).

other than that located at the hindmost part are not so large. Accordingly, the correlation-diagram is expected to show emphasizing the same tendency of the deviations as the spacing-diagram of the subordinate species having the clear structure, the big-eye tuna. Taking this fact into consideration, I examined the actually obtained correlation-diagram, but no symptom suggesting any other relation worthy to be described was found out except the high observed-value at $k = 33$, which showed the relation of the hooked-individuals near the both terminal parts of a row and was thought to have not so high significance.

*Yellow-fin tuna—Albacore* : Like the big-eye tuna, the hooked-individuals of the albacore also clearly form several schools. Accordingly, the same fact as mentioned above is expected. And this is supported by the peaks observable at $k = 6$, around 13, 19, around 25 and 32. But the correlation-diagram obtained actually adds another fact than those expected preliminarily, *i.e.*, the individuals of both species are so repulsively distributed that, to see generally, only less individuals than expected are hooked in the lots spaced by a width shorter than six lots from any occupied one

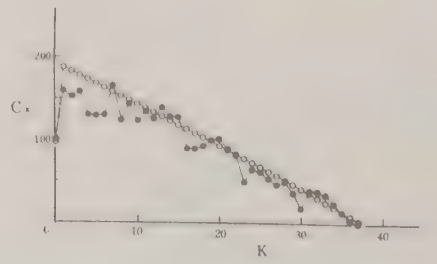



Fig. 29—Y A—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 4, Series Ⅰ : unit is 10 consecutive basket width = *ca.* 2 km).

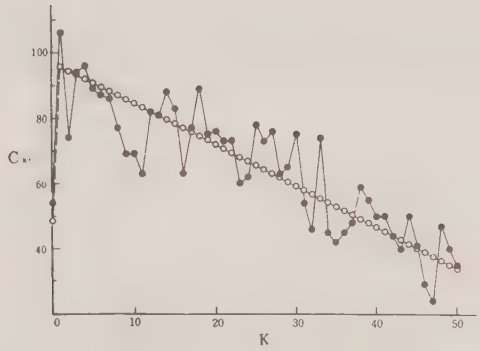



Fig. 29—Y A—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 4, Series Ⅱ : unit is 5 consecutive basket width= *ca.* 1 km).

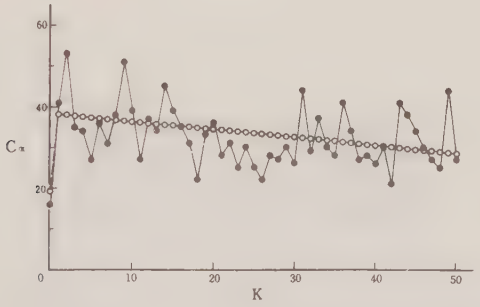



Fig. 29—Y A—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 4, Series Ⅲ : unit is 2 consecutive basket width= *ca.* 0.4 km).

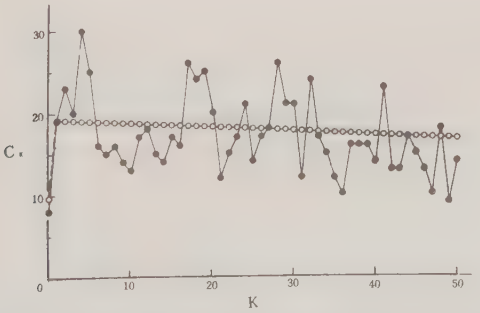



Fig. 29—Y A—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 4, Series Ⅳ : unit is 1 basket width=*ca.* 0.2 km).

by the individuals of each other's species, although as many individuals as expected, when the individuals of both species are distributed independently, are hooked by the same lots occupied by the individuals of each other's species.

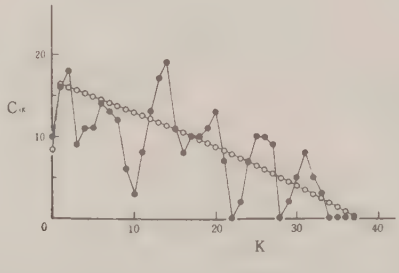



Fig. 29—B A—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of big-eye tuna and albacore, in contrast with that of the theoretically estimated ones (Example 4, Series Ⅰ : unit is 10 consecutive basket width = *ca.* 2 km).

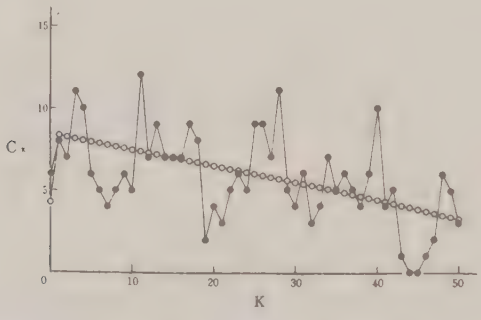



Fig. 29—B A—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of big-eye tuna and albacore, in contrast with that of the theoretically estimated ones (Example 4, Series Ⅱ : unit is 5 consecutive basket width = *ca.* 1 km).

*Big-eye tuna—Albacore* : As already mentioned above, the hooked-individuals of the big-eye tuna clearly form five schools, but the correlation-diagram is expected to be inclined to show the positional relation of schools of the albacore between the school of the big-eye tuna located at the position around the 350th basket, *i.e.*, the peaks of the observed-values are expected to be found at $k$ = 0, 10, 20, 25 and 31, because the population sizes of all schools of the big-eye tuna other than that located at the hindmost part are extremely small. But, in the actually obtained correlation-diagram, one more peak is observable around $k = 6 \sim 8$, although this does not exceed the theoretical-values. And this group of high observed-values is expected to represent the relation of positions of the schools of the albacore between some other schools of the big-eye tuna. And the symptom supporting it is easily found out from the positions of the schools shown in Figs. 9—B and 9—A. Besides, no symptom suggesting the

presence of any other structure can be found out, because of clear school-formation of the hooked-individuals of both species.

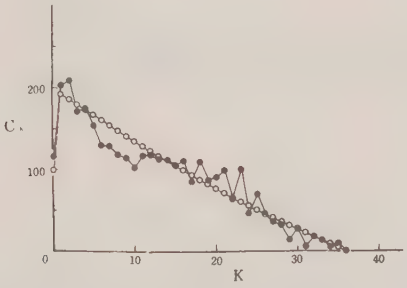



Fig. 30—Y B—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 5, Series Ⅰ : unit is 10 consecutive basket width= *ca.* 2 km).

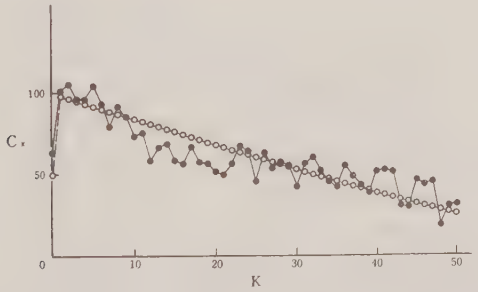



Fig. 30—Y B—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 5, Series Ⅱ : unit is 5 consecutive basket width= *ca.* 1 km).

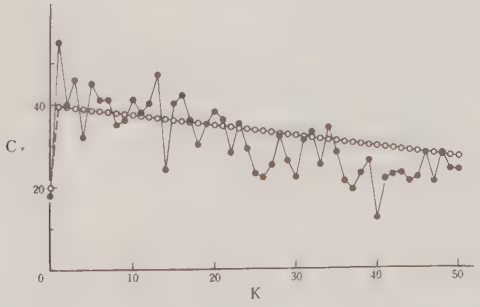



Fig. 30—Y B—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 5, Series Ⅲ : unit is 2 consecutive basket width= *ca.* 0.4 km).

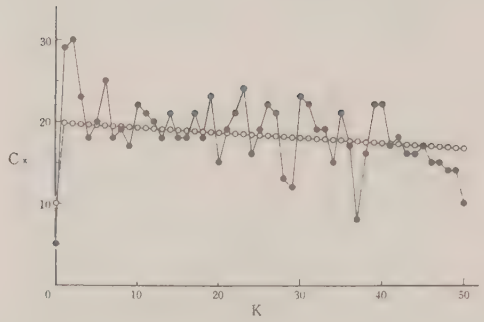



Fig. 30—Y B—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 5, Series Ⅳ : unit is 1 basket width=*ca.* 0.2 km).

## Example 5

*Yellow-fin tuna—Big-eye tuna* : Taking the influence of the strong gradient of the distribution into consideration, I found that the hooked-individuals of the yellow-fin tuna seemed to contain two schools, the centers of which were located at the positions around the 100th and the 350th baskets respectively, the latter of which was constituted of many individuals and covering a wider range than the former; while generally speaking, the hooked-individuals of the big-eye tuna formed a scattered school covering a space as wide as 250 baskets (= 50 km). And examining the actually obtained correlation-diagram, I found that the both terminal parts of the school of the big-eye tuna were overlapping the schools of the yellow-fin tuna and the distance between the overlapping parts was estimated to be 200 baskets (= 40 km). And the following series of analyses are added for the purpose of finding out the relation of the positions within the overlapping parts, although significance of the pattern suggested from these series of analyses is somewhat doubtful. These diagrams show that more individuals are hooked by the hooks spaced by a width shorter than three or four baskets (0.6 ~ 0.8 km) from any occupied hook by the individual of each other's species, *i.e.*, the hooked-individuals of both species are inclined to take the same micro-habitats or to form the common clusters of the subordinate orders.

*Yellow-fin tuna –Albacore* : Relatively many individuals of the albacore are hooked, and the most of the hooked-individuals form a single school scattered widely and covering a space from the 80th to the 240th basket. Accordingly, the correlation-diagram is expected preliminarily to represent that the schools of both species are not distributed overlapping each other but the heavily-occupied parts by the individuals of each other's species are spaced by a width from 50 to 170 baskets or thereabout (10 ~34 km), that is to say in short, the individuals of both species are repulsively distributed. And well coincident patterns with the above-mentioned preliminary consideration is represented in the actually obtained correlation-diagram.

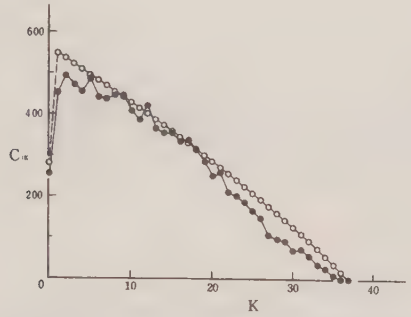



Fig. 30—Y A—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 5, Series Ⅰ : unit is 10 consecutive basket width= *ca.* 2 km).

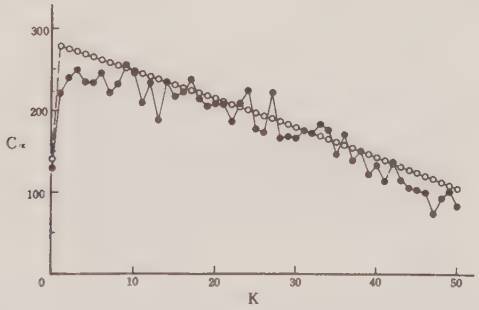



Fig. 30—Y A—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 5, Series Ⅱ : unit is 5 consecutive basket width= *ca.* 1 km).

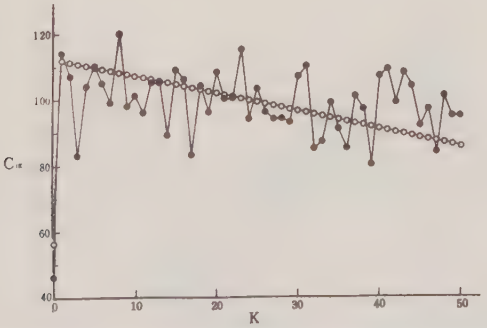



Fig. 30—Y A—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 5, Series Ⅲ : unit is 2 consecutive basket width= *ca.* 0.4 km).

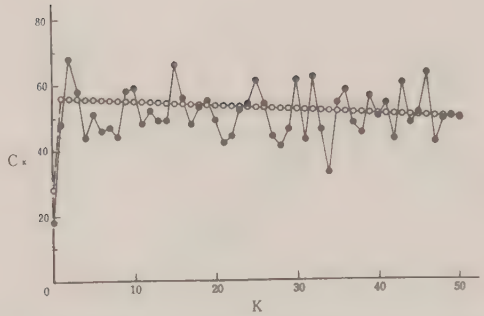



Fig. 30—Y A—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 5, Series Ⅳ : unit is 1 basket width = *ca.* 0.2 km).

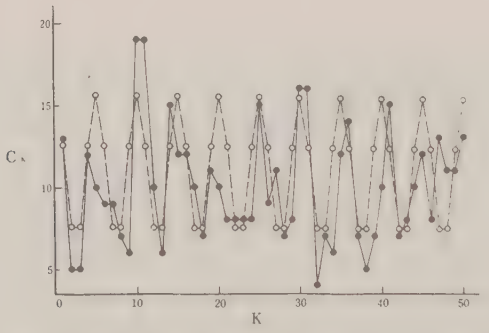



Fig. 30—Y A—Ⅴ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 5, Series Ⅴ : unit is one hook-interval width = *ca.* 40 m).

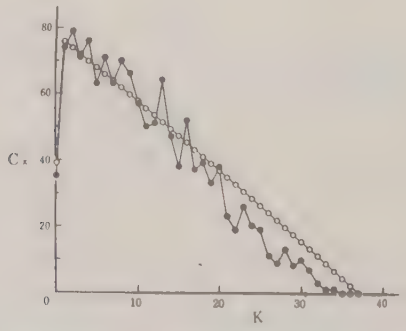



Fig. 30—B A—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of big-eye tuna and albacore, in contrast with that of the theoretically estimated ones (Example 5, Series Ⅰ : unit is 10 consecutive basket width = *ca.* 2 km).

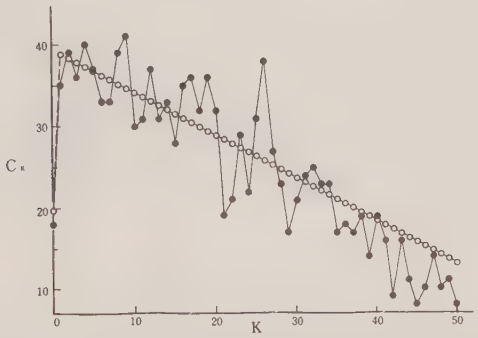



Fig. 30—B A—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of big-eye tuna and albacore, in contrast with that of the theoretically estimated ones (Example 5, Series Ⅱ : unit is 5 consecutive basket width= *ca.* 1 km).

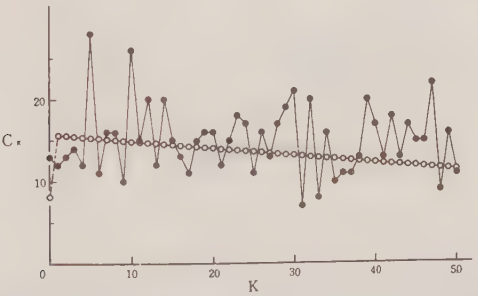



Fig. 30—B A—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of big-eye tuna and albacore, in contrast with that of the theoretically estimated ones (Example 5, Series Ⅲ : unit is 2 consecutive basket width= *ca.* 0.4 km).

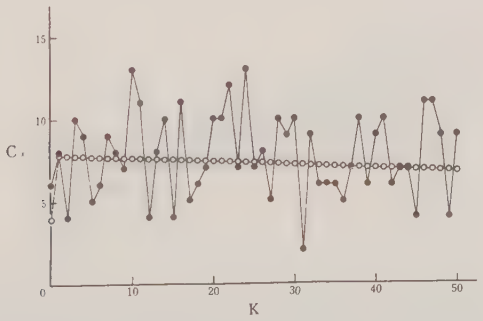



Fig. 30—B A—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of big-eye tuna and albacore, in contrast with that of the theoretically estimated ones (Example 5, Series Ⅳ : unit is 1 basket width=*ca.* 0.2 km).

*Big-eye tuna—Albacore* : Not so many individuals as expected from independent distribution are hooked by the same or adjoining lots (lot = 10 consecutive baskets) occupied by the individuals of each other's species; this fact alludes to the repulsive relation between both species affecting in a short range; while aggregative relation affecting to the long range is suggested from the continuously high general-tendency of the observed-values and this is thought to be caused as the results of schooling-tendency of the individuals of the albacore, because the big-eye tuna is scattered in a wider range than the albacore.

## Example 6

*Yellow-fin tuna—Big-eye tuna* : To see generally, the yellow-fin tuna forms two schools located at the ranges respectively from the 85th to the 135th basket and from

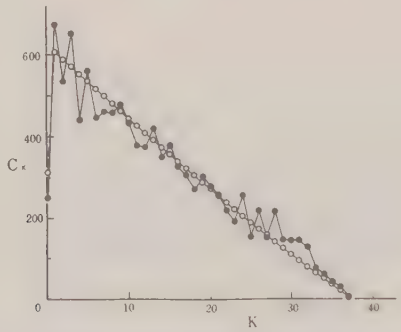



Fig. 31—Y B—I. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 6, Series I : unit is 10 consecutive basket width = *ca.* 2 km).

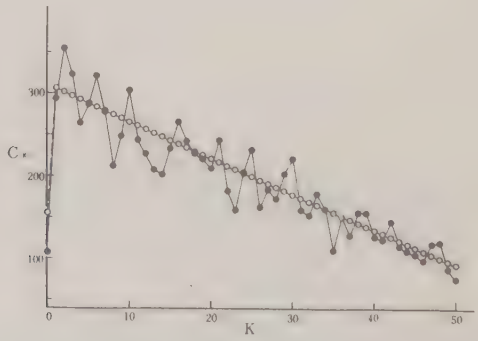



Fig. 31—Y B—II. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 6, Series II : unit is 5 consecutive basket width = *ca.* 1 km).

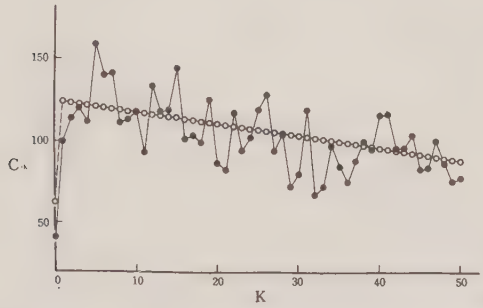



Fig. 31—Y B—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 6, Series Ⅲ : unit is 2 consecutive basket width = *ca.* 0.4 km).

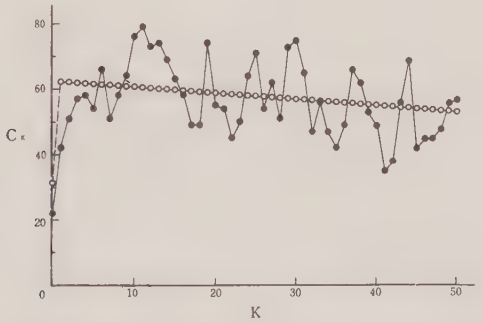



Fig. 31—Y B—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 6, Series Ⅳ : unit is 1 basket width = *ca.* 0.2 km).

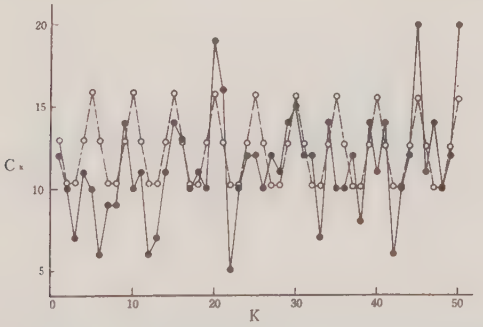



Fig. 31—Y B—Ⅴ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 6, Series Ⅴ : unit is one hook-interval width = *ca.* 40 m).

the 275th to the 360th one; while the hooked-individuals of the big-eye tuna form also two schools respectively located at the ranges from the first to the 60th basket and from the 200th to the hindmost one. Accordingly, the observed-values of the correlation-diagram in the range from $k = 0$ to 5 or thereabout are expected to exceed slightly the estimated ones. Besides them, on the positions of the schools, the observed-values around $k = 13$ and 28 are also expected to be higher than the estimated ones. On the other hand, two-lot periodicity is suggested in the distribution pattern of the hooked-individuals of the yellow-fin tuna while strong periodicity of four-lot width and a little weak two-lot one are clearly observable in the distribution pattern of the hooked-individuals of the big-eye tuna. Therefore, the observed-values in the correlation-diagram are also expected to show two-lot periodicity. And examining on the actually obtained correlation-diagram, I found that the deviations of the observed-values showed quite the same features as the expected ones, except the fact that the expectant high observed-values around $k = 13$ were not so distinct. And this difference is thought to be due to the structure of the subordinate orders of respective species. Then, for the purpose of confirming the structures in the projected distribution pattern causing this difference, whether the individuals of the big-eye tuna are hooked in the parts spaced by a width as long as 13 lots (= 25 km) from any part occupied heavily by the individuals of the yellow-fin tuna or not is examined. And I found that only as many as a half of the assumed positions were occupied heavily by the individuals of the big-eye tuna. The following series of the correlation-diagrams add the information about the spatial relation within a short range, and they suggest that less individuals than expected are hooked in the baskets spaced by an interval shorter than 10 baskets (= 2 km) from any occupied basket by the individuals of each other's species.

*Yellow-fin tuna—Albacore* : A school of the albacore covers a space from the 40th to the 240th basket. Accordingly, one of the yellow-fin tuna school located in the

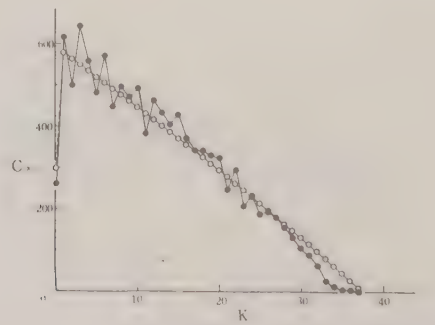



Fig. 31—YA—I. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 6, Series I : unit is 10 consecutive basket width = *ca.* 2 km).

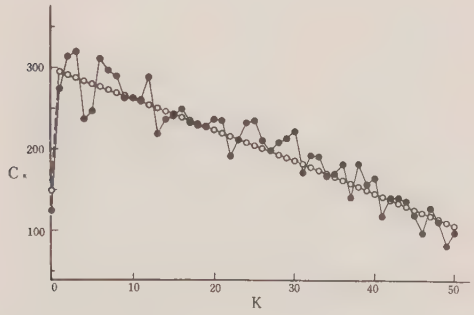



Fig. 31—Y A—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 6, Series Ⅱ : unit is 5 consecutive basket width= *ca.* 1 km).

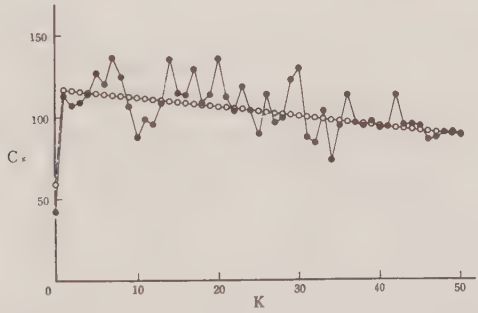



Fig. 31—Y A—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 6, Series Ⅲ : unit is 2 consecutive basket width= *ca.* 0.4 km).

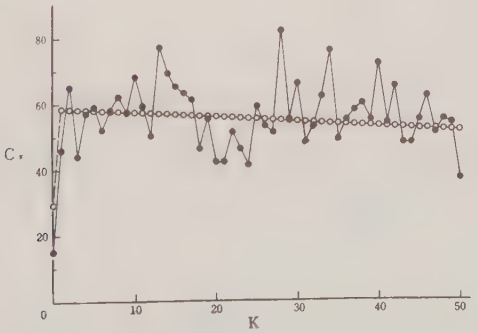



Fig. 31—Y A—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 6, Series Ⅳ : unit is 1 basket width=*ca.* 0.2 km).

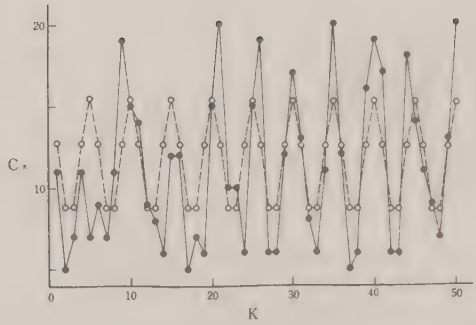



Fig. 31—Y A—V. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 6, Series V : unit is one hook-interval width = *ca.* 40 m).

range from the 85th to the 135th basket is hooked in the common part covered by the school of the albacore, while the other school of the yellow-fin tuna is hooked out of the school of the albacore. These facts are expected to raise the observed-values in the range from $k = 0$ to 5. Moreover, the following facts are deduced out from the relation between the positions of the schools of each other's species: 1) let us consider the parts spaced by $k$ towards the same direction as the hauling from the school of the yellow-fin tuna located in the range from the 85th to the 135th basket. When $0 < k < 10$, all the parts are covered by the school of the albacore; while when $10 < k < 15$, some parts; but when $15 < k$, no part is located in it. 2) And let us consider the similar parts from the other school of the yellow-fin tuna located in the range from the 275th to the 360th basket. No part is put in the school of the albacore regardless of $k$. 3) But let us consider the parts spaced by $k$ towards the counter direction to the hauling from the school of the yellow-fin tuna hooked in the range from the 85th to the 135th basket. When $0 < k < 4$, all the parts are covered by the school of the albacore; when $4 < k < 10$, only a part is located in it; while when $10 < k$, no part is put in it. And 4) let us consider the similar parts from the other school of the yellow-fin tuna located in the range from the 275th to the 360th basket. When $0 < k < 4$, no part is put in the school of the albacore, but when $4 < k < 12$, only a part; when $12 < k < 20$, whole part; while when $20 < k < 32$, some parts are put in the school of the albacore; while when $32 < k$, no part is put in it. Therefore, the observed-values in the range from $k = 0$ to 20 or thereabout are expected to exceed the theoretical-values, then they decrease more sharply than the theoretical-values. But some short-periodic deviations are also expected, because in company with the facts easily assumable from the above-mentioned descriptions the individuals of the yellow-fin tuna are not distributed uniformly throughout the parts covered by the schools of the yellow-fin tuna. And the actually obtained correlation-diagram of Series I reveals that the deviations of the observed-values in this diagram

are fearly explained from the above-mentioned prediction.

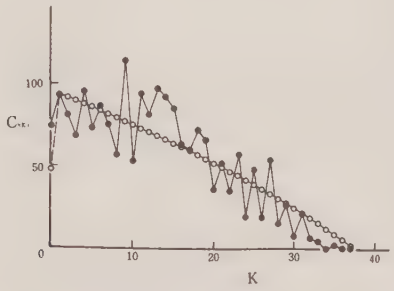



Fig. 31—B A—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of big-eye tuna and albacore, in contrast with that of the theoretically estimated ones (Example 6, Series Ⅰ : unit is 10 consecutive basket width = *ca.* 2 km).

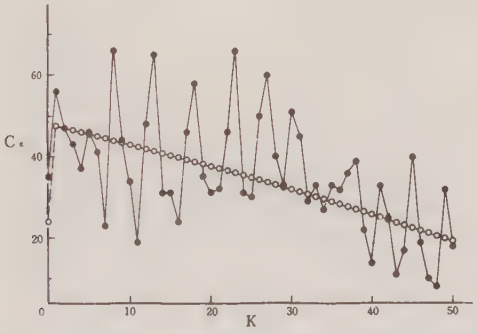



Fig. 31—B A—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of big-eye tuna and albacore, in contrast with that of the theoretically estimated ones (Example 6, Series Ⅱ : unit is 5 consecutive basket width = *ca.* 1 km).

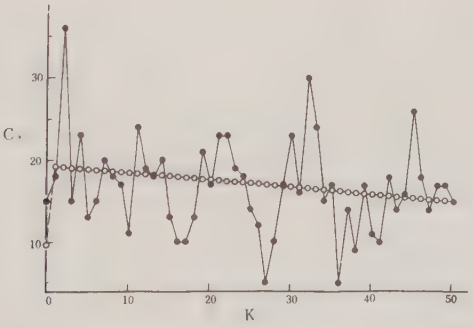



Fig. 31—B A—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of big-eye tuna and albacore, in contrast with that of the theoretically estimated ones (Example 6, Series Ⅲ : unit is 2 consecutive basket width = *ca.* 0.4 km).

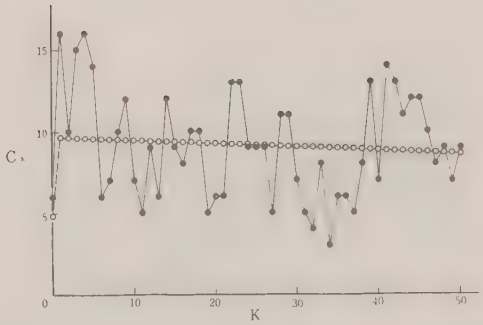



Fig. 31—B A—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of big-eye tuna and albacore, in contrast with that of the theoretically estimated ones (Example 6, Series Ⅳ : unit is 1 basket width=*ca.* 0.2 km).

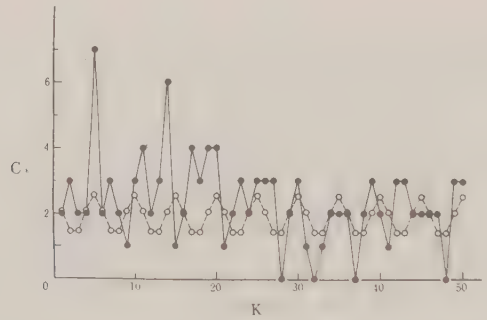



Fig. 31—B A—Ⅴ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of big-eye tuna and albacore, in contrast with that of the theoretically estimated ones (Example 6, Series Ⅴ : unit is one hook-interval width=*ca.* 40 m).

*Big-eye tuna—Albacore* : As mentioned above, the schools of the big-eye tuna cover the spaces from the first to the 60th basket and from the 200th to the hindmost one, while the school of the albacore covers a space from the 40th to the 240th basket. Accordingly, the correlation-diagram is expected to show clearly repulsive relation. And the actually obtained correlation-diagram shows the features coinciding well with this prediction. Besides the general tendency, the observed-values, including those of the following series, deviate severely showing short periodicity. And these deviations are thought to indicate the relation of the positions of the narrow but heavily-occupied parts and are chiefly due to the scarcity of the hooked-individuals of respective species and partly to the fact that both species show rather distinct periodicity of deviations.

## Example 7

*Yellow-fin tuna—Big-eye tuna* : The hooked population of the yellow-fin tuna of

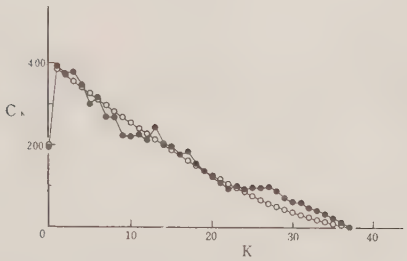



Fig. 32—Y B—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 7, Series Ⅰ : unit is 10 consecutive basket width= *ca.* 2 km).

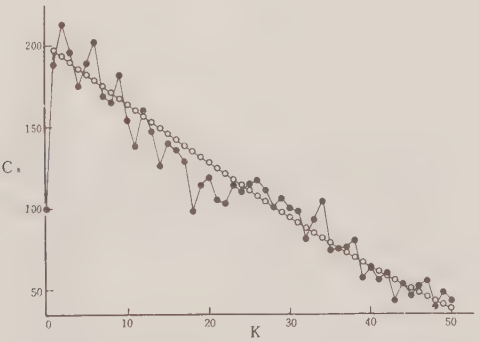



Fig. 32—Y B—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 7, Series Ⅱ : unit is 5 consecutive basket width= *ca.* 1 km).

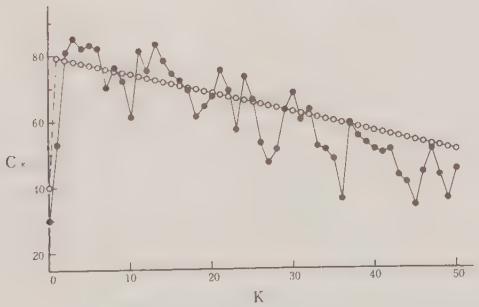



Fig. 32—Y B—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 7, Series Ⅲ : unit is 2 consecutive basket width= *ca.* 0.4 km).

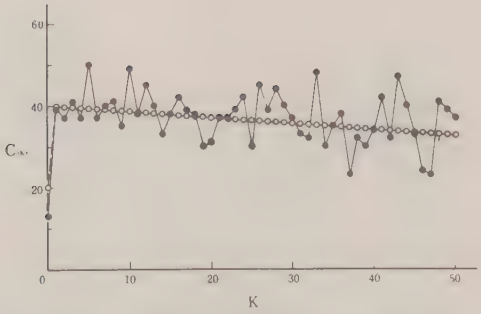



Fig. 32—Y B—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 7, Series Ⅳ : unit is 1 basket width = *ca.* 0.2 km).

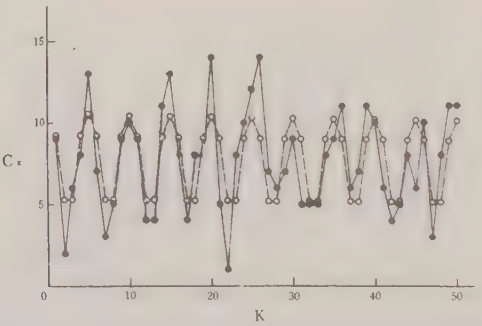



Fig. 32—Y B—Ⅴ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 7, Series Ⅴ : unit is one hook-interval width = *ca.* 40 m).

this example contains three schools hooked respectively at the positions around the 50th, the 200th and the 350th baskets, of which the second one is constituted of the largest population; while the hooked population of the big-eye tuna contains two schools and the most heavily-occupied parts in respective schools are the 100th and the 300th baskets. Therefore, the intervals between the schools of each other's species are expected to take 50, 100 and 250 baskets (= 10, 20 and 50 km). But each of the schools covers a space wider than 50 baskets (= 10 km); accordingly, some parts of the schools of each other's species are overlapping. Therefore, high observed-values are expected to occur in the range from $k = 0$ to 5 lots (lot = 10 consecutive baskets) or longer, but there is no school of the big-eye tuna located at the position around the 200th basket, where the largest school of the yellow-fin tuna is hooked. Consequently, the above-mentioned group of the observed-values is expected to exceed not so largely or sometimes is afraid to be not exceeding the theoretical ones. And

the deviations coinciding well with the above-mentioned predictions are found out in the actually obtained correlation-diagram in the range from $k = 0$ to 7. The assumable high observed-values in the correlation-diagram around $k = 10$ lots are thought to be derived from the largest school of the yellow-fin tuna. But this group of high observed-values is expected to be not so strongly exceeding while covering a wide range of $k$, because all of the three schools causing this group of high observed-values (a school of the yellow-fin tuna and two schools of the big-eye tuna) are widely dispersed. These estimations are also coincident well with the deviations of the observed-values in the correlation-diagram obtained actually. And two pairs of schools each constituted of different species, the school of the yellow-fin tuna located at the position around the 50th basket——the big-eye tuna one around the 300th basket and a school of the yellow-fin tuna around the 350th basket —— the big-eye tuna one around the 100th basket, are expected to cause a group of high observed-values around $k = 25$. And this group is also expected to cover a wide range, because a school of the big-eye tuna in the former pair and a school of the yellow-fin tuna in the latter pair are widely dispersed. The deviation of the observed-values in the actually obtained correlation-diagram supporting this is clearly observable, but the observed deviation seems to be somewhat severer than the assumed one. And no symptom suggesting any other structure is observable in the correlation-diagram obtained actually.

*Yellow-fin tuna—Albacore* : The largest school of the albacore is hooked at the position around the 50th basket and the second one is at the position around the 250th basket, while the smallest one is at the position around the 150th basket. Accordingly, the parts around the 50th basket are occupied by the schools of both species, although a school of the yellow-fin tuna hooked there is not so large. And this fact is represented in the correlation-diagram as the slightly high observed-values in the range from $k = 0$ to 2; but examining the relation more in detail by the aids of the following series of analyses, I found that the individuals were not so frequently hooked in the same or adjoining baskets but frequently hooked in the baskets spaced by three baskets (= 0.6 km) from any occupied one by the individual of each other's

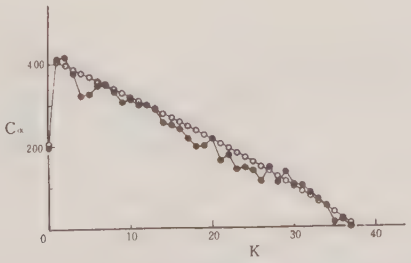



Fig. 32—Y A—I. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 7, Series I : unit is 10 consecutive basket width = *ca.* 2 km).

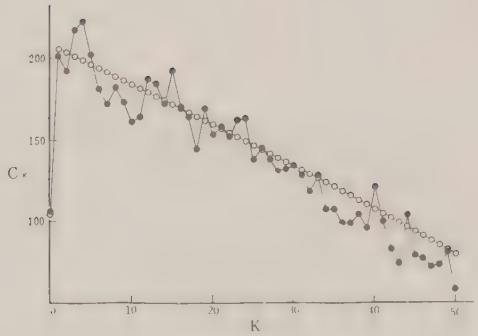



Fig. 32—Y A—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 7, Series Ⅱ : unit is 5 consecutive basket width = *ca.* 1 km).

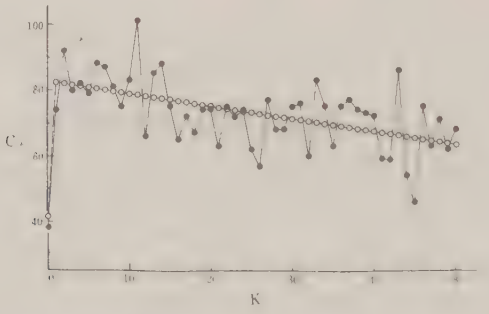



Fig. 32—Y A—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 7, Series Ⅲ : unit is 2 consecutive basket width = *ca.* 0.4 km).

Fig. 32—Y A—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 7, Series Ⅳ : unit is 1 basket width = *ca.* 0.2 km).

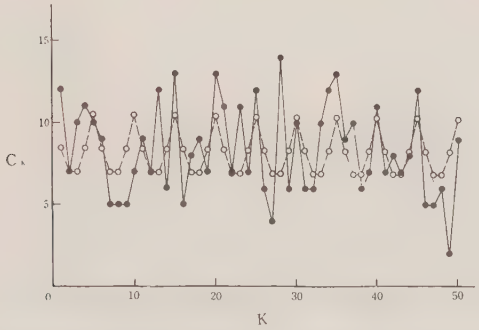



Fig. 32—Y A—Ⅴ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 7, Series Ⅴ : unit is one hook-interval width=*ca.* 40 m).

species. On the other hand, the centers of the schools of each other's species are spaced by 50, 100, 150, 200 and 300 baskets (= 10, 20, 30, 40 and 60 km), *i.e.*, nearly each 50-basket interval (10 km); but each of the expectant peak is supposed to be not discontinuous but successive, owing to being influenced by the fact that when $k$ is increased into the width, which combinations of the individuals of the yellow-fin tuna and the big-eye tuna from a certain pair of the schools begin to decrease, combinations from other pairs of the schools begin to appear, because the schools of the yellow-fin tuna cover wide ranges. Therefore, the correlation-diagram is expected to show such a pattern that the individuals of both species are distributed independently of each other's species. And no remarkable relation other than that assumed preliminarily is observable from the correlation-diagram obtained actually.

*Big-eye tuna——Albacore* : The distribution patterns of both species suggest that the heavily-occupied parts by the individuals of each other's species are frequently spaced

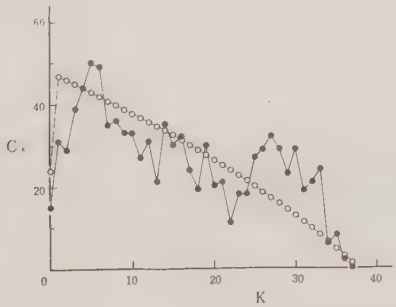



Fig. 32—B A—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of big-eye tuna and albacore, in contrast with that of the theoretically estimated ones (Example 7, Series Ⅰ : unit is 10 consecutive basket width= *ca.* 2 km).

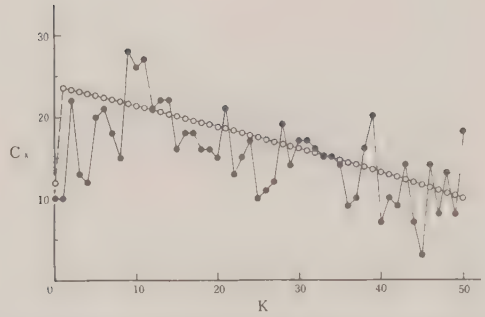



Fig. 32—B A—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of big-eye tuna and albacore, in contrast with that of the theoretically estimated ones (Example 7, Series Ⅱ : unit is 5 consecutive basket width = *ca.* 1 km).

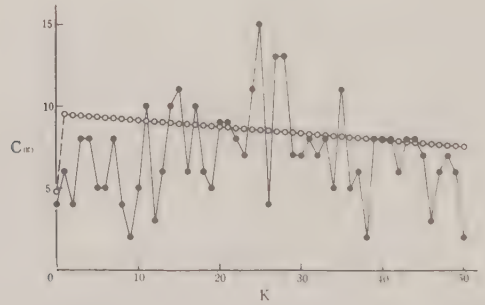



Fig. 32—B A—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of big-eye tuna and albacore, in contrast with that of the theoretically estimated ones (Example 7, Series Ⅲ : unit is 2 consecutive basket width = *ca.* 0.4 km).

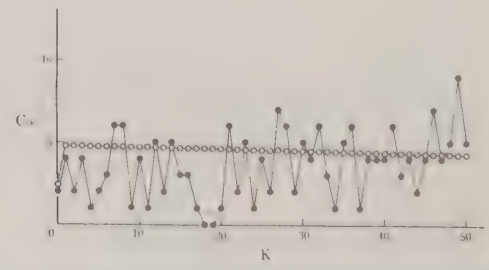



Fig. 32—B A—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of big-eye tuna and albacore, in contrast with that of the theoretically estimated ones (Example 7, Series Ⅳ : unit is 1 basket width = *ca.* 0.2 km).

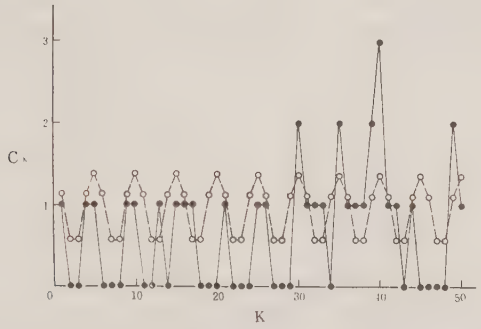



Fig. 32—B A—Ⅴ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of big-eye tuna and albacore, in contrast with that of the theoretically estimated ones (Example 7, Series Ⅴ : unit is one hook-interval width=*ca.* 40 m).

by 5 and 15 lots (10 and 30 km), consequently groups of rather high observed-values in the correlation-diagram are expected to be observable at $k = 5$ and around 15 lots; while the most heavily-occupied part by the individuals of the big-eye tuna is located at the position around the 50th basket; this is expected to cause a group of the observed-values around $k = 25$ exceeding largely the corresponding estimated ones. And no fact worthy to be described newly is deducible from the actually obtained correlation-diagram, except the fact easily assumable from the distribution patterns of respective species. And it may well be said, as the conclusion of the relation between the hooked positions of both species in this example, that the individuals of both species are hooked not at the same parts but in the adjoining ones.

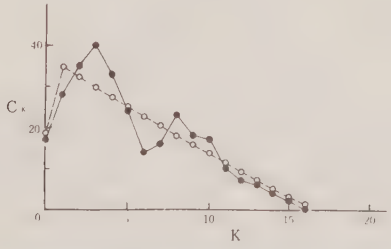



Fig. 33—Y B—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 8, Series Ⅰ : unit is 10 consecutive basket width= *ca.* 2 km).

## Example 8

*Yellow-fin tuna——Big-eye tuna* : The extreme scarcity of the hooked-individuals of the big-eye tuna does not allow me to give so high significance upon the facts deducible from the correlation-diagram, despite of the fact that the correlation-dia-

gram rather clearly shows that, as assumable from the distribution patterns of both species, relatively many individuals are hooked in the lots spaced by a width as long as 3 or 8 lots ( 6 or 16 km) from any lot occupied heavily by the individuals of each other's species.

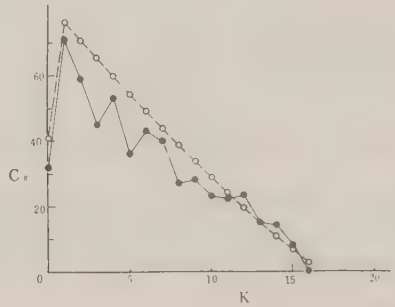



Fig. 33—Y A—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 8, Series Ⅰ : unit is 10 consecutive basket width= *ca.* 2 km).

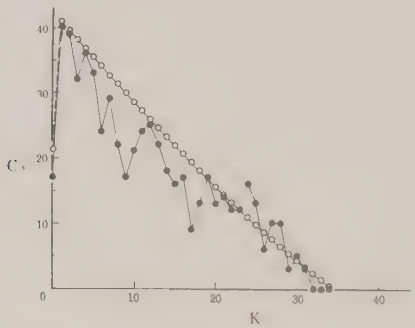



Fig. 33—Y A—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 8, Series Ⅱ : unit is 5 consecutive basket width= *ca.* 1 km).

*Yellow-fin tuna——Albacore* : A slight but widely affecting repulsive tendency is suggested. And the continuously lower observed-values support to give some significance; while the small difference in the observed-values from the estimated ones and the scarcity of the hooked-individuals of the albacore do not accept to give so high significance as to be impressed simply from the magnitude of the observed-values and the estimated ones.

*Big-eye tuna——Albacore* : Some patterns may seem to be deducible but the scarcity of the hooked-individuals of both species introduces the unnegligible influence of

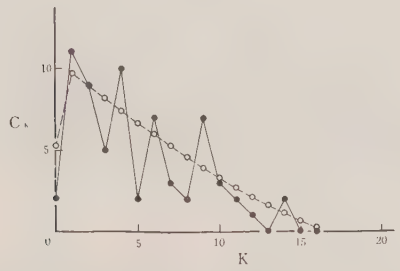



Fig. 33—B A—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of big-eye tuna and albacore, in contrast with that of the theoretically estimated ones (Example 8, Series Ⅰ : unit is 10 consecutive basket width = *ca.* 2 km).

accidental error and no significance can be given to the deduced facts.

## Example 9

This example is not suitable for the analyses on the correlations of the hooked positions between the individuals of the different species, because the extreme scarcity of the hooked-individuals of the albacore makes it impossible to give any consideration upon the correlation between the hooked positions of the albacore and those of the others; moreover it is also hard to get any correlation-diagram free from the severe influence of accidental error, because not so many individuals of the big-eye tuna are hooked.

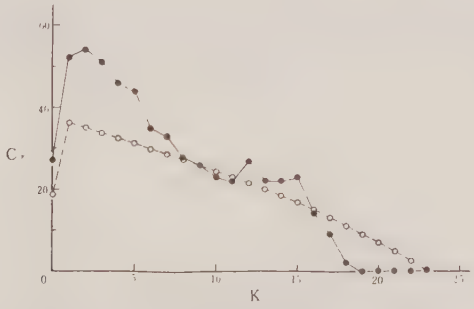



Fig. 34—Y B—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 9, Series Ⅰ : unit is 10 consecutive basket width = *ca.* 2 km).

*Yellow-fin tuna——Big-eye tuna* : The hooked population of the yellow-fin tuna contains two schools; while the catch of the big-eye tuna is constituted of a single school to which an individual spaced by *ca.* 70 baskets (= 15 km) is attached. Accordingly, a school of the yellow-fin tuna occupies the common habitat or forms the

common school with the big-eye tuna, while almost no individual of the big-eye tuna is hooked in the part where the other school of the yellow-fin tuna is hooked. But the actually obtained correlation-diagram adds such an information about the correlation of the hooked positions that the individuals of the big-eye tuna are not uniformly distributed in the school and the center of the distribution of the big-eye tuna is biased a width as long as 40 baskets (= 8 km) from that of a school of the yellow-fin tuna.

## Example 10

*Yellow-fin tuna——Big-eye tuna* : Most of the hooked-individuals of the yellow-fin tuna are distributed forming three schools respectively located at the positions around the 210th, the 270th and the 345th baskets; while the hooked-individuals of the big-eye tuna are scattered all over a row, but they are rather densely hooked

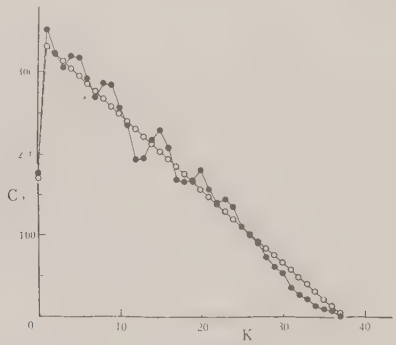



Fig. 35—Y B—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 10, Series Ⅰ : unit is 10 consecutive basket width =*ca.* 2 km).

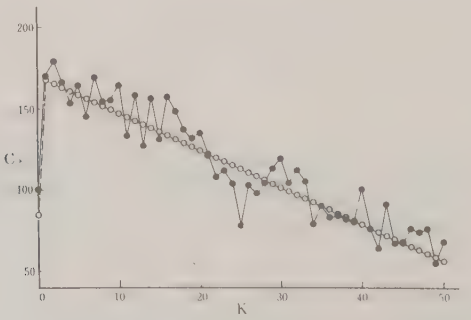



Fig. 35—Y B—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 10, Series Ⅱ : unit is 5 consecutive basket width= *ca.* 1 km).

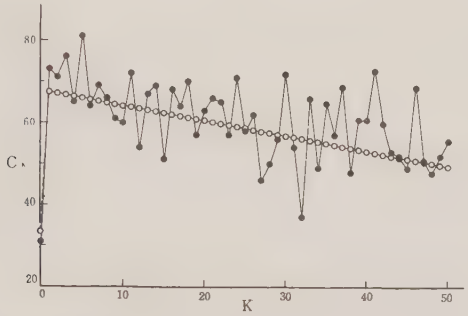



Fig. 35—Y B—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 10, Series Ⅲ : unit is 2 consecutive basket width= *ca.* 0.4 km).

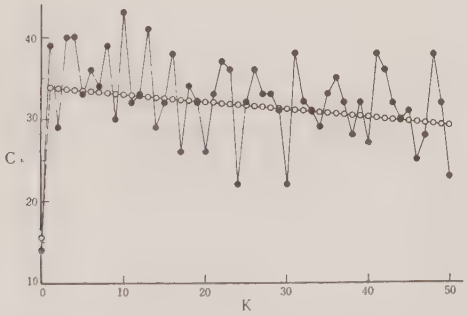



Fig. 35—Y B—Ⅳ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 10, Series Ⅳ : unit is 1 basket width=*ca.* 0.2 km).

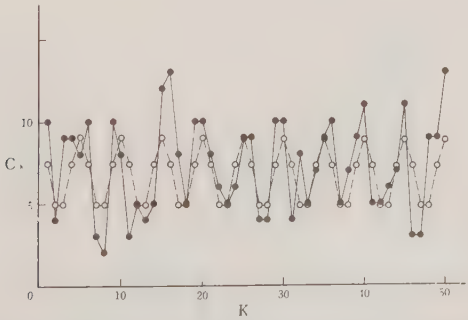



Fig. 35—Y B—Ⅴ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 10, Series Ⅴ : unit is one hook-interval width=*ca.* 40 m).

in the ranges from the 10th to the 125th and from the 230th to the hindmost basket, especially dense population is observable at the positions around the 65th, the 115th and the range from the 270th to the 305th basket. Therefore, a school of the yellow-fin tuna is hooked in the lots occupied heavily by the individuals of the big-eye tuna, and another school of the yellow-fin tuna is hooked in the lots where the individuals of the big-eye tuna are a little densely hooked, while the other school of the yellow-fin tuna is located between two groups of heavily-occupied lots by the individuals of the big-eye tuna. Accordingly, the observed-values in the correlation-diagram in the range from $k = 0$ to 2, which is the range of the observed-values in the spacing-diagram of the yellow-fin tuna exceeding the estimated-values and is thought to be the average width of the yellow-fin tuna schools, are also expected to exceed the estimated ones. Next, from the positions of the schools or heavily-occupied parts by the individuals of respective species, the observed-values at $k = 5$, 9, 15, about 20, 23 and 28 are expected to show higher values. And the actually obtained correlation-diagram shows quite coinciding pattern with the above-mentioned prediction, except that any symptom supporting the occurrence in the expectant high observed-value at $k = 28$ can not be found out. And this difference is thought to be due to the fact that, when the gradient is taken into consideration, the schooling tendency of the yellow-fin tuna school located at the position around the 345th basket can not be regarded to be so strong. And the correlation-diagrams, not only that of Series I but also including the following series, are examined more in detail, yet no symptom suggesting any other structure worthy to be described is found out except the short-periodic deviation to which we can not give so high significance.

*Yellow-fin tuna——Albacore* : The hooked-individuals of the albacore are distributed forming three schools located at the positions respectively around the 45th basket, in the ranges from the 110th to the 175th basket and from the 265th to the 300th basket. Therefore, the observed-values in the correlation-diagram in the range from $k = 0$ to

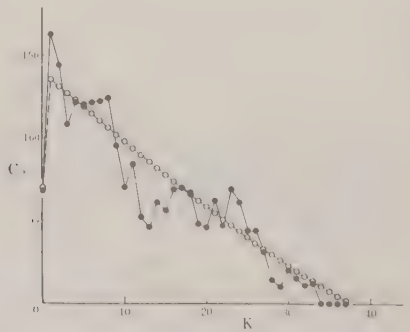



Fig. 35—Y A—I. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 10, Series I : unit is 10 consecutive basket width $=ca.$ 2 km).

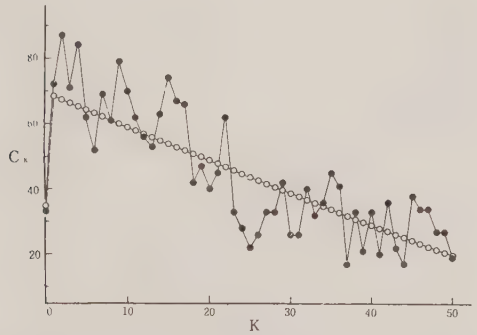



Fig. 35—Y A—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 10, Series Ⅱ : unit is 5 consecutive basket width = *ca.* 1 km).

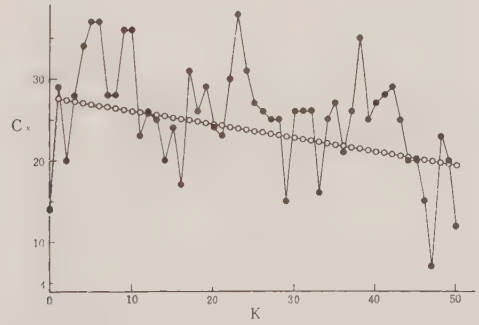



Fig. 35—Y A—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 10, Series Ⅲ : unit is 2 consecutive basket width = *ca.* 0.4 km).

2, which is thought to be the width of the yellow-fin tuna school, are expected to exceed the theoretical-values. And from the positions of the centers of the schools of respective species, the observed-values at $k = 7$, 13, 17, 21, 23 and 30 in the correlation-diagram are expected to exceed the theoretical ones; and also the width of each group of high observed-values is expected to be wide, because each school of the albacore covers a space nearly as wide as the interval between the adjoining centers of the schools of the yellow-fin tuna, moreover some differences in the positions showing high observed-values in the correlation-diagram from the above-mentioned $k$ are expected. Keeping these results of the prediction in mind, we examined the actually obtained correlation-diagram. Then, we will notice the fact easily that the actually obtained correlation-diagram takes quite the same features as those assumed preliminarily and no symptom suggesting any other structure worthy to be described can be found out.

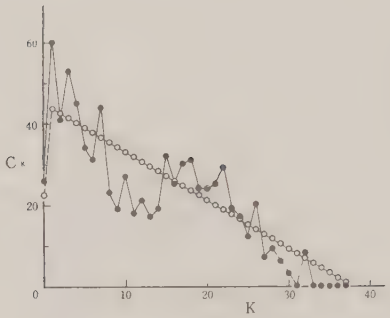



Fig. 35—B A—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of big-eye tuna and albacore, in contrast with that of the theoretically estimated ones (Example 10, Series Ⅰ : unit is 10 consecutive basket width =*ca.* 2 km).

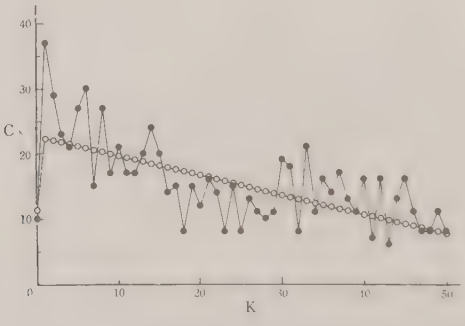



Fig. 35—B A—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of big-eye tuna and albacore, in contrast with that of the theoretically estimated ones (Example 10, Series Ⅱ : unit is 5 consecutive basket width= *ca.* 1 km).

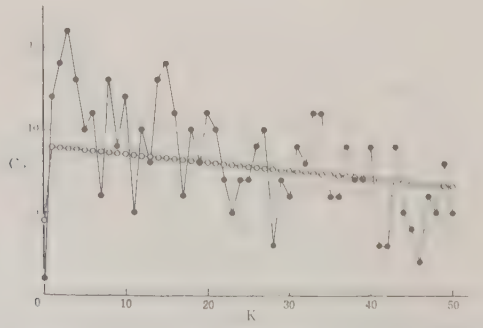



Fig. 35—B A—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of big-eye tuna and albacore, in contrast with that of the theoretically estimated ones (Example 10, Series Ⅲ : unit is 2 consecutive basket width= *ca.* 0.4 km).

*Big-eye tuna——Albacore* : As assumable from the distribution patterns of respective species, the parts, where the individuals of the big-eye tuna are densely hooked, are covered by two schools of the albacore. Moreover, the peripheries of the other school of the albacore are overlapping the parts where the individuals of the big-eye tuna are densely hooked. Therefore, the distinct aggregative-tendency is expected to be suggested. And the continuously high observed-values in the range from $k = 0$ to 4 in the actually obtained correlation-diagram support these predictions; while the high observed-value in the diagram at $k = 7$ is thought to be caused by the positional relation among respective schools of the subordinate order, but not so high significance can be given to it for fear of the severe influence of accidental error. And the other group of high observed-values around $k = 20$ indicates the relation of positions between the schools of the big-eye tuna and the albacore except one of the latters located near the middle of a row.

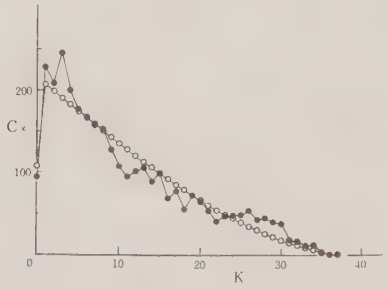



Fig. 36—Y B—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 11, Series Ⅰ : unit is 10 consecutive basket width $=ca.$ 2 km).

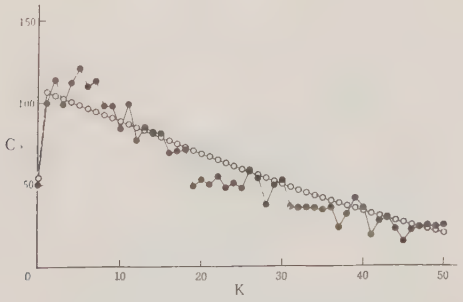



Fig. 36—Y B—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 11, Series Ⅱ : unit is 5 consecutive basket width $=$ *ca.* 1 km).

## Example 11

*Yellow-fin tuna——Big-eye tuna* : No remarkable structure can be found out except the fact that the distances between the individuals of the yellow-fin tuna and of the big-eye tuna frequently take the width not so long or about 300 baskets because the individuals of the big-eye tuna are hooked scattered throughout a row against the fact that the population of the yellow-fin tuna contains two schools spaced by a width as long as 300 baskets each other.

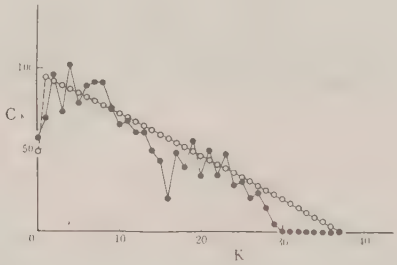



Fig. 36—Y A—I. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 11, Series I : unit is 10 consecutive basket width =*ca.* 2 km).

*Yellow-fin tuna——Albacore* : The hooked-individuals of the albacore form a single diversed school. Accordingly, relatively clear relation is expected against the scarcity of the hooked-individuals of the albacore. And the actually obtained correlation-diagram suggests, as expected, that the distances between the individuals of both species frequently take 20 (= 40 km) and a little shorter than 10 lots (= 20 km), *i.e.*, school of the albacore is located between the schools of the yellow-fin tuna.

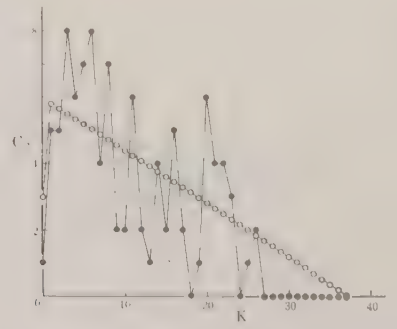



Fig. 36—B A—I. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of big-eye tuna and albacore, in contrast with that of the theoretically estimated ones (Example 11, Series I : unit is 10 consecutive basket width *ca.* 2 km).

*Big-eye tuna*——*Albacore* : The distribution patterns of both species suggest that it is difficult to expect any clear relation. Moreover, if suspected, the scarcity of the hooked-individuals of both species makes it impossible to give any significance.

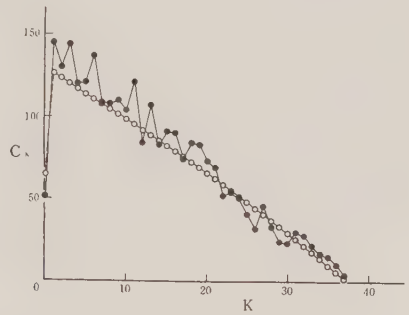



Fig. 37—Y B—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 12, Series Ⅰ : unit is 10 consecutive basket width =*ca.* 2 km).

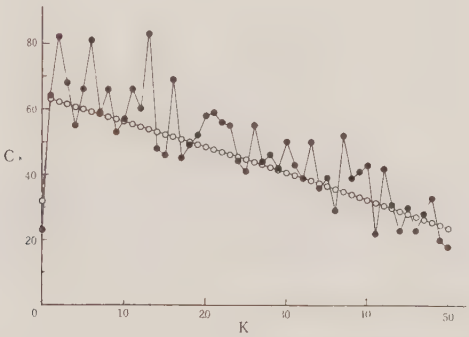



Fig. 37—Y B—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 12, Series Ⅱ : unit is 5 consecutive basket width= *ca.* 1 km).

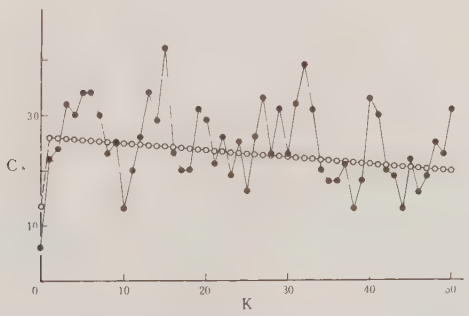



Fig. 37—Y B—Ⅲ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and big-eye tuna, in contrast with that of the theoretically estimated ones (Example 12, Series Ⅲ : unit is 2 consecutive basket width= *ca.* 0.4 km).

### Example 12

*Yellow-fin tuna——Big-eye tuna* : Most of the hooked-individuals of the yellow-fin tuna are thought to form many small schools scattered throughout a row showing 6～8 basket periodicity; while the hooked-individuals of the big-eye tuna, which are not so many enough as deducible some patterns of significance, are self-spacingly scattered throughout a row. Accordingly, the distribution patterns of both species tell us that the clear relation is hardly expectable. Therefore, we can not give high significance upon the deviation —— consequently the decoded relation —— in the correlation-diagram, although the deviations of the observed-values in the actually obtained correlation-diagram may seem to allude to aggregative-pattern affecting widely; and for the short-periodic deviations in this diagram, I wish to give no description, because the same reasons mentioned above are far strongly influential.

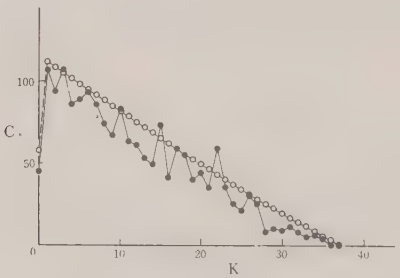



Fig. 37—Y A—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 12, Series Ⅰ : unit is 10 consecutive basket width =*ca.* 2 km).

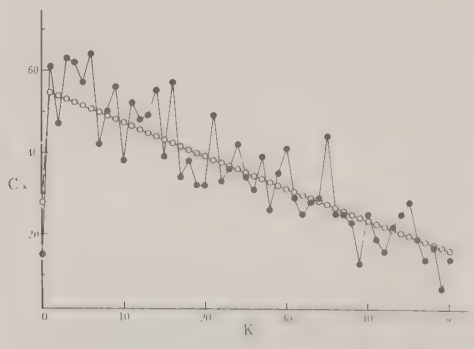



Fig. 37—Y A—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of yellow-fin tuna and albacore, in contrast with that of the theoretically estimated ones (Example 12, Series Ⅱ : unit is 5 consecutive basket width= *ca.* 1 km).

*Yellow-fin tuna——Albacore* : Clear relation is hardly expectable, because not so many individuals of the albacore are hooked moreover they are scattered self-spacingly throughout a row. And even if any relation is obtained, not so high significance as

superficially impressed from the magnitude of the observed-values can be given to it. But some high observed-values can be found in the actually obtained correlation-diagram, but it seems to be difficult to give high significance because of the scarcity of the hooked-individuals in company with the facts that the observed-values exceed the estimated ones neither so largely nor so continuously, moreover they do not show so clear periodicity. From the following series of analyses, it may well be said that less individuals than expected are hooked in the baskets spaced by a width shorter than five baskets but more individuals are hooked in the baskets spaced by $7A$ baskets ($A$ is a positive integer but not so large) from any basket occupied by the individuals of each other's species. And these facts are thought to be, at least partly, due to the periodicity in the distribution pattern of the yellow-fin tuna.

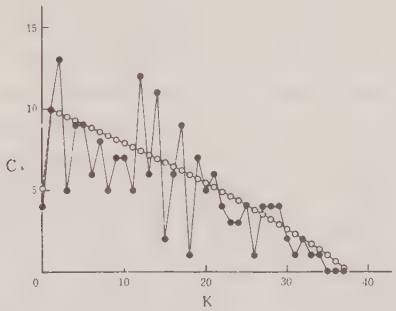



Fig. 37—B A—Ⅰ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of big-eye tuna and albacore, in contrast with that of the theoretically estimated ones (Example 12, Series Ⅰ : unit is 10 consecutive basket width $=ca.$ 2 km).

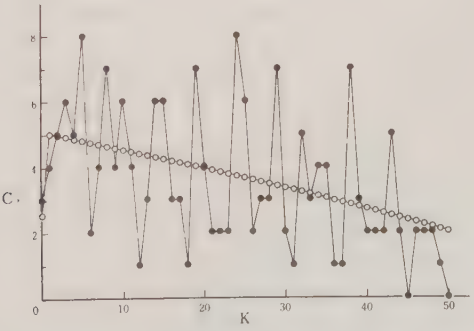



Fig. 37—B A—Ⅱ. The deviation of the observed numbers of the individual-pairs of respective widths and constituted of big-eye tuna and albacore, in contrast with that of the theoretically estimated ones (Example 12, Series Ⅱ : unit is 5 consecutive basket width $=$ $ca.$ 1 km).

*Big-eye tuna——Albacore* : The deviation of the observed-values in the correlation-

diagram showing some clear relation can hardly be expected, because the hooked-individuals of each species are not so many enough, moreover they are scattered rather self-spacingly. But the observed-values in the actually obtained correlation-diagram in the range $10 < k < 20$ seem to be higher than the estimated ones, which may seem to allude to a repulsive relation. And also severely deviating 2.5-lot periodicity of them can be found out. But, for fear of unnegligible influence of accidental error due to poor catch, whether we can give any significance to it or not is highly doubtful.

## 2. Summarized results of the correlation analysis

*Yellow-fin tuna——Big-eye tuna* : The correlation of the hooked positions of both species observable within a short range is thought to be more strongly affected by the social relation between the individuals of each other's species, while that extending to wide range is rather strongly influenced by the distribution patterns of both species to consider with the large scale. Therefore, the interests of this report should be naturally paid to the correlation within a short range, but the scarcity of the hooked-individuals of the big-eye tuna makes it impossible to analyze any correlation of significance but that extending to a wide range, although the large population size of the hooked-individuals of the yellow-fin tuna superficially raises the observed-values falsely high enough as if to be deducible significant correlation even within a short range. Accordingly, I was obliged to restrict the discussion on the relation between the hooked positions of the individuals to consider with the large scale. And these correlations deduced from respective examples are classified into as follows:

A. The individuals of each species form rather clear and widely covering schools, and aggregative-relation can be suspected between the individuals of both species.
   1) All the individuals of both species are hooked in *entirely* the common parts·····Example 2
   2) All the individuals of a certain species (big-eye tuna) are hooked in the common parts with the individuals of the other species (yellow-fin tuna), while there are some other parts occupied only by the individuals of the latter species·····Examples 1 and 9
   3) Most of the individuals of both species are hooked in some common parts, while a part of the individuals of both species is hooked separately in each other's part in a row·····Examples 6, 7 and 10, of which the last example has some characteristics of the examples classifiable into column (6)
   4) Most of the individuals of both species are hooked in some common parts, while other individuals of both species are hooked almost separately but some peripherial parts of the schools of the different species are overlapping····· None

B. The individuals of each species form rather clear schools but rather repulsive

relation is suspected between the individuals of each other's species.

5) Schools of both species are hooked in *entirely* the different parts……No example shows such perfectly repulsive relation

6) Schools of both species are hooked in *almost* the different parts while some peripherial parts of the schools of the different species are overlapping…… Example 5 (roughly speaking, the common cluster-formation of the subordinate order is suspected).

C. No clear relation is observable, because the individuals of each one or both of the two species do not form any clear school, but are scattered.

7) The individuals of a species are scattered, while those of the other species form clear schools …… Examples 3, 4, 11 and 12, of which the last one shows the feature classifiable into the next column

8) The individuals of both species are scattered …… There is no example classified into this group, although Example 12 shows the relation somewhat resembling this type.

Thus, no repulsive relation is admitted, but rather aggregative relation is suggested in many examples.

*Yellow-fin tuna——Albacore* : The scarcity of the hooked-individuals of the albacore makes it impossible to give any consideration upon the correlation within a short range; and the significance of the deduced relation extending to wide space also does not rid of the influence due to the same fact, but the general tendencies of the correlation of the hooked positions of the individuals of the yellow-fin tuna and the albacore of respective examples are, for reference' sake, classified into as follows:

A 1) No example shows such perfectly aggregative relation.
2) Example 3
3) Examples 2, 6 and 10
4) Example 7

B 5) Examples 5 and 11
6) There is no example classified into this column.

C 7) Examples 4 and 8
8) Example 12

Thus, the relation of the hooked positions between the individuals of the yellow-fin tuna and the albacore seems to be less aggregative or more repulsive than that between the yellow-fin tuna and the big-eye tuna. And this fact may be more or less due to the fact that food habits and body size of the individuals of the yellow-fin tuna and those of the albacore differ rather markedly, while those of the big-eye tuna are rather similar to those of the yellow-fin tuna.

*Big-eye tuna——Albacore* : Examples 1 and 9 are omitted from the consideration, because of the extreme scarcity of the hooked-individuals of the albacore; while the number of gears used in Example 8 is not so large enough and this example is also

omitted. For the other examples, the hooked population-sizes of both species are not so large enough as to be deducible any relation capable of giving some significance. But the following description may be shown as the conclusion of this relation, although significance of some of them is doubtful.

A 1) No example shows such perfectly aggregative relation.
2) Also no example shows such relation.
3) Exapmle 2
4) Examples 4 and 10, of which the relation observable in the former one is too complicated to be classified simply into this type, but may well be said that the individuals of both species are distributed rather independently of each other's species, while the latter one shows somewhat strongly aggregative tendency.

B 5) Example 7 This example is inclined to show the relation classified into column (3).
6) Example 6 This example has some characteristics classified into the next column.

C 7) Examples 3, 5 and 11, of which the second one shows the relation somewhat resembling that of column (1) and at the same time repulsive tendency within a short range is observable against the fact that the last one has some characteristics of column (8).
8) Example 12

Thus, as slightly repulsive relation as or a little more repulsive one than that between the hooked-individuals of the yellow-fin tuna and those of the albacore is observable between the individuals of the big-eye tuna and the albacore.

The above-mentioned three relations summarized, it may well be concluded that the aggregative relation is observable between the individuals of the yellow-fin tuna and the big-eye tuna while the individuals of the albacore are distributed rather repulsively against the individuals of the yellow-fin tuna and the big-eye tuna, moreover strongly to the latter, despite of the fact that the hooked-population sizes of the yellow-fin tuna are large while those of the big-eye tuna and the albacore are small. And these relations are thought to be strongly reflecting on the relation of food habits and body sizes observable among the individuals of these three species.

# Part Ⅱ Interval analysis (Modified type of the order method)

## Method of Analysis

The spacing method does not touch on the fact whether some of the inserted hooks are occupied or not, and this sometimes makes it into confusion to translate the results of the analysis into the actual pattern, although the same fact has such advantages as being able to give consideration upon the relation extending to a wide range compared with the unit-length. Accordingly, changing the mind, I have deviced out another trial. This method treats of the length of the interval from any hooked-individual to the next one, *i.e.*, whether some of the inserted hooks are occupied or not is taken into consideration. Therefore, this method is thought to be one of the modified types of the method called the order method or the n-th neighbouring one, in which the frequency distribution of the distance from any individual to the n-th neighbouring individual is treated. And recently there have been deviced out many methods (MORISITA 1954 and THOMPSON 1956) but most of them are applicable to the distribution in space and any of them is scarcely applicable to the analysis on the distribution along a line, moreover no one satisfy all or most of the peculiar conditions specific to long-line gears. Accordingly, the constructing-method and the processes of the exclusion of the influence of the gradient of occupied-rate due to soaking time and that of the difference in the occupied-rates due to that of the depth levels of the hooks will be described in detail step by step, because I am afraid that the description given in the first report was too short to understand clearly, moreover no example of the analysis actually adopting this method was illustrated.

### 1. Original form

This is the group of the formulae in which the theoretical process of the construction is most easily and clearly recognizable. But this is applicable to only the ideal conditions, in which neither significant gradient nor significant difference in the occupied-rate due to soaking time and depth levels of hooks is expected.

Let us set that $N$ individuals are scattered by chance along a row of gears constituted of $m$ consecutive baskets of equal length and having four hooks a basket. And by the same manner as the spacing analysis, $k$ is represented as $a(H+1)+R$, when it is separated into the part divisible by the length of a basket and remainder. Here, when $R = 0$, there are $H$ hooks in the $(i+a)th$ basket, each of which is spaced by $k$ hook-intervals from any hook in the $ith$ basket as shown in Table 2; while when $R \neq 0$, there are $(H - R)$ hooks in the $(i + a)th$ basket and $(R - 1)$ hooks in the

Table 7. Probability of occurrence in two occupied hooks spaced by $k$ hook-intervals each other and inserted no occupied hook, with particular reference to partial probabilities, when one starts to count $k$ from respective hooks in the $ith$ basket at respective $R$. (As a process of understanding easily the construction of the formulae of the interval analysis, in which neither significant gradient nor significant difference in occupied rate due to soaking time and depth levels of the hooks is expected.)

| R | Order of hook in the $i$-$th$ basket starting to count $k$ | Order of hook spacing $k$ from it | Occupied probability of both terminal hooks | Consecutively unoccupied prob. of residual hooks in the $i$-$th$ basket | That of inserted baskets |
|---|---|---|---|---|---|
| 0 | 1 | 1 | $P^2$ | $q^3$ | $q^{i(a-1)}$ |
| | 2 | 2 | $P^2$ | $q^2$ | $q^{i(a-1)}$ |
| | 3 | 3 | $P^2$ | $q^1$ | $q^{i(a-1)}$ |
| | 4 | 4 | $P^2$ | $q^0$ | $q^{i(a-1)}$ |
| 1 | 1 | 2 | $P^2$ | $q^3$ | $q^{i(a-1)}$ |
| | 2 | 3 | $P^2$ | $q^2$ | $q^{i(a-1)}$ |
| | 3 | 4 | $P^2$ | $q^1$ | $q^{i(a-1)}$ |
| | 4 | B | 0 | — | — |
| 2 | 1 | 3 | $P^2$ | $q^3$ | $q^{i(a-1)}$ |
| | 2 | 4 | $P^2$ | $q^2$ | $q^{i(a-1)}$ |
| | 3 | B | 0 | — | — |
| | 4 | 1 | $P^2$ | $q^0$ | $q^{ia}$ |
| 3 | 1 | 4 | $P^2$ | $q^3$ | $q^{i(a-1)}$ |
| | 2 | B | 0 | — | — |
| | 3 | 1 | $P^2$ | $q^1$ | $q^{ia}$ |
| | 4 | 2 | $P^2$ | $q^0$ | $q^{ia}$ |
| 4 | 1 | B | 0 | — | — |
| | 2 | 1 | $P^2$ | $q^2$ | $q^{ia}$ |
| | 3 | 2 | $P^2$ | $q^1$ | $q^{ia}$ |
| | 4 | 3 | $P^2$ | $q^0$ | $q^{ia}$ |

| R | That of hooks in the $(i+a)$-$th$ basket* arranged earlier than a terminal | Product of these prob. | Range of $i$ capable of varying: Smallest | Largest |
|---|---|---|---|---|
| 0 | $q^0$ | $P^2\ q^{ia-1}$ | 1 | $(M-a)$ |
| | $q^1$ | $P^2\ q^{ia-1}$ | 1 | $(M-a)$ |
| | $q^2$ | $P^2\ q^{ia-1}$ | 1 | $(M-a)$ |
| | $q^3$ | $P^2\ q^{ia-1}$ | 1 | $(M-a)$ |
| 1 | $q^1$ | $P^2\ q^{ia}$ | 1 | $(M-a)$ |
| | $q^2$ | $P^2\ q^{ia}$ | 1 | $(M-a)$ |
| | $q^3$ | $P^2\ q^{ia}$ | 1 | $(M-a)$ |
| | — | 0 | — | — |
| 2 | $q^2$ | $P^2\ q^{ia+1}$ | 1 | $(M-a)$ |
| | $q^3$ | $P^2\ q^{ia+1}$ | 1 | $(M-a)$ |
| | — | 0 | — | — |
| | $q^0$ | $P^2\ q^{ia}$ | 1 | $(M-a-1)$ |
| 3 | $q^3$ | $P^2\ q^{ia+2}$ | 1 | $(M-a)$ |
| | — | 0 | — | — |
| | $q^0$ | $P^2\ q^{ia+1}$ | 1 | $(M-a-1)$ |
| | $q^1$ | $P^2\ q^{ia+1}$ | 1 | $(M-a-1)$ |
| | — | 0 | — | — |
| 4 | $q^0$ | $P^2\ q^{ia+2}$ | 1 | $(M-a-1)$ |
| | $q^1$ | $P^2\ q^{ia+2}$ | 1 | $(M-a-1)$ |
| | $q^2$ | $P^2\ q^{ia+2}$ | 1 | $(M-a-1)$ |

* For the columns, in which $i$ varies from 1 to $(m-a-1)$, the $(i+a+1)th$ is substituted for the $(i+a)$th.

$(i+a+1)th$ basket. But there are $a$ buoy-lines, consequently $(k-a-1)$ inserted hooks, between the two hooks spaced by $k$ hook-intervals each other and one is in the $ith$ basket and the other is in the $(i+a)th$ basket; while there are $(a+1)$ buoy-lines, consequently $(k-a-2)$ inserted hooks, between the two hooks spaced by $k$ hook-intervals each other and one is in the $ith$ and the other is in the $(i+a+1)th$ basket. Accordingly, the probabilities of all the inserted hooks unoccupied continuously are $q^{(k-a-1)}$ and $q^{(k-a-2)}$, respectively, here $P=\frac{N}{Hm}$ and $q=1-P$. Therefore, the expectant number of the two occupied-hooks spaced by $k$ hook-intervals each other and without any occupied inserted-hook, $\Psi_{(k)}$, is represented as follows:

at $R=0$

$$\Psi_{(k)}=H(m-a)P^2 q^{(k-a-1)} \quad (15)$$

while at $R \neq 0$

$$\Psi_{(k)}=(H-R)(m-a)P^2 q^{(k-a-1)}+(R-1)(m-a-1)P^2 q^{(k-a-2)}$$
$$=P^2 q^{(k-a-2)}[(H-R)(m-a)q+(R-1)(m-a-1)] \quad (16)$$

Notes:

1) Test-method, examining the significance of the difference in the observed-values from the estimated ones at respective $k$, has not yet found out.

2) Total number of $\Psi_{(k)}$, $\sum_{k=1}^{m(H+1)-2} \Psi_{(k)}$, is limited to be as large as $(N-1)$ which is as equal as the number of the intervals nipped by two individuals among $N$ individuals hooked along a line.

3) Accordingly, this method can be effectively tried only when $N$ is large.

4) Some computation error due to $q$ is expected to be rather severely affecting to the theoretical-values, especially those at longer $k$.

5) When $P$ is not so small, the estimated-values decrease rapidly with increase in $k$, which results that there is no need or impossible to compute $\Psi_{(k)}$ at longer $k$.

6) Accordingly, the distribution pattern observable even in a considerably wide range is analyzible by only one series of analysis, the unit-length of which is so short as to a hook-interval. But, it is undesirable to adopt a long unit-length.

7) It is far easier to count the observed-value of this method than that of the spacing one.

## 2. Exclusion of the influence of the difference in the occupied-rates due to that of the fishing depths of the hooks

The formulae, in which the influence of this factor is taken into consideration, take the different forms with that in the number of hooks attaching to each basket. Therefore, the constructing-process of the formulae applicable to the gears constituted of a series of main-lines attaching to four hooks a basket is illustrated, as an example, because the gears used in this study are constituted of a connected series of

main-lines attaching to four hooks a basket.

Let us set that $N_1$ and $N_2$ individuals are distributed by chance along shallower hooks and deeper ones of a row of gears constituted of $m$ consecutive baskets attaching to four hooks a basket. For the purpose of understanding the constructing-process easily, it seems better to treat the probability of the occurrence in the two hooks spaced by $k$ hook-intervals each other and without any occupied hook separating into 1) the occupied probability of both terminal hooks, 2) the unoccupied probability of the hooks in the $ith$ basket located in the range latter than the hook starting to count $k$, 3) the successively unoccupied probability of the inserted baskets and 4) the unoccupied probability of the hooks in the $(i+a)th$ or the $(i+a+1)th$ basket coming earlier than the ending hook to count $k$. Represent $k$ as $a(4+1)+R$, and the above-mentioned partial probabilities when starting to count $k$ from respective hooks in the $ith$ basket at respective $R$ are represented in Table 8. And the probability of occurrence in the two occupied-hooks spaced by $k$ hook-intervals each other and without any occupied inserted-hook, starting to count $k$ from respective hooks in the $ith$ basket at respective $R$, is the product of the four probabilities arranged horizontally in Table 8. Here, when one hook is located in the $ith$ basket and the other

Table 8. Probability of occurrence in two occupied hooks spaced by $k$ hook-intervals each other and inserted no occupied hook, with particular reference to partial probabilities, when one starts to count $k$ from respective hooks in the $ith$ basket at respective $R$. (As a process of understanding easily the construction of the formulae of the interval analysis, in which the influence of the difference in the occupied rates due to that of the fishing depths of the hooks is taken into consideration.)

| R | Order of hook in the $i$-$th$ basket starting to count $k$ | Order of hook spacing $k$ from it | Occupied probability of both terminal hooks | Consecutively unoccupied prob. of residual hooks in the $i$-$th$ basket | That of inserted baskets |
|---|---|---|---|---|---|
| 0 | 1 | 1 | $P_1^2$ | $q_1q_2^2$ | $(q_1q_2)^{2(a-1)}$ |
| | 2 | 2 | $P_2^2$ | $q_1q_2$ | $(q_1q_2)^{2(a-1)}$ |
| | 3 | 3 | $P_2^2$ | $q_1$ | $(q_1q_2)^{2(a-1)}$ |
| | 4 | 4 | $P_1^2$ | 1 | $(q_1q_2)^{2(a-1)}$ |
| 1 | 1 | 2 | $P_1P_2$ | $q_1q_2^2$ | $(q_1q_2)^{2(a-1)}$ |
| | 2 | 3 | $P_2^2$ | $q_1q_2$ | $(q_1q_2)^{2(a-1)}$ |
| | 3 | 4 | $P_1P_2$ | $q_1$ | $(q_1q_2)^{2(a-1)}$ |
| | 4 | B | 0 | — | — |
| 2 | 1 | 3 | $P_1P_2$ | $q_1q_2^2$ | $(q_1q_2)^{2(a-1)}$ |
| | 2 | 4 | $P_1P_2$ | $q_1q_2$ | $(q_1q_2)^{2(a-1)}$ |
| | 3 | B | 0 | — | — |
| | 4 | 1 | $P_1^2$ | 1 | $(q_1q_2)^{2a}$ |
| 3 | 1 | 4 | $P_1^2$ | $q_1q_2^2$ | $(q_1q_2)^{2(a-1)}$ |
| | 2 | B | 0 | — | — |
| | 3 | 1 | $P_1P_2$ | $q_1$ | $(q_1q_2)^{2a}$ |
| | 4 | 2 | $P_1P_2$ | 1 | $(q_1q_2)^{2a}$ |
| 4 | 1 | B | 0 | — | — |
| | 2 | 1 | $P_1P_2$ | $q_1q_2$ | $(q_1q_2)^{2a}$ |
| | 3 | 2 | $P_2^2$ | $q_1$ | $(q_1q_2)^{2a}$ |
| | 4 | 3 | $P_1P_2$ | 1 | $(q_1q_2)^{2a}$ |

| R | That of hooks in the $(i+a)$-$th$ basket arranged earlier than a terminal | Product of these prob. | Range of $i$ capable of varying | |
|---|---|---|---|---|
| | | | Smallest | Largest |
| 0 | 1 | $P_1^2q_2$ $(q_1q_2)^{2a-1}$ | 1 | $(M-a)$ |
| | $q_1$ | $P_2^2q_1$ $(q_1q_2)^{2a-1}$ | 1 | $(M-a)$ |
| | $q_1q_2$ | $P_2^2q_1$ $(q_1q_2)^{2a-1}$ | 1 | $(M-a)$ |
| | $q_1q_2^2$ | $P_1^2q_2$ $(q_1q_2)^{2a-1}$ | 1 | $(M-a)$ |
| 1 | $q_1$ | $P_1P_2$ $(q_1q_2)^{2a}$ | 1 | $(M-a)$ |
| | $q_1q_2$ | $P_2^2$ $(q_1q_2)^{2a}$ | 1 | $(M-a)$ |
| | $q_1q_2^2$ | $P_1P_2$ $(q_1q_2)^{2a}$ | 1 | $(M-a)$ |
| 2 | $q_1q_2$ | $P_1P_2q_2$ $(q_1q_2)^{2a}$ | 1 | $(M-a)$ |
| | $q_1q_2^2$ | $P_1P_2q_2$ $(q_1q_2)^{2a}$ | 1 | $(M-a)$ |
| | 1 | $P_1^2$ $(q_1q_2)^{2a}$ | 1 | $(M-a-1)$ |
| 3 | $q_1q_2^2$ | $P_1^2q_2^2$ $(q_1q_2)^{2a}$ | 1 | $(M-a)$ |
| | 1 | $P_1P_2q_1$ $(q_1q_2)^{2a}$ | 1 | $(M-a-1)$ |
| | $q_1$ | $P_1P_2q_1$ $(q_1q_2)^{2a}$ | 1 | $(M-a-1)$ |
| 4 | 1 | $P_1P_2q_1q_2(q_1q_2)^{2a}$ | 1 | $(M-a-1)$ |
| | $q_1$ | $P_2^2q_1^2$ $(q_1q_2)^{2a}$ | 1 | $(M-a-1)$ |
| | $q_1q_2$ | $P_1P_2q_1q_2(q_1q_2)^{2a}$ | 1 | $(M-a-1)$ |

is in the $(i+a)th$ one, "$i$" varies from 1 to $(m-a)$, while for the rests of it, "$i$" varies from 1 to $(m-a-1)$. Accordingly, the expectant number is estimative from the following formulae:

at $R=0$

$$\Psi_{(k)}=2(m-a)(q_1q_2)^{(2a-1)}(P_1^2q_2+P_2^2q_1) \quad \cdots\cdots (17)$$

at $R=1$

$$\Psi_{(k)}=(m-a)(q_1q_2)^{2a}(2P_1P_2+P_2^2) \quad \cdots\cdots (18)$$

at $R=2$

$$\Psi_{(k)}=2(m-a)(q_1q_2)^{2a}P_1P_2q_2+(m-a-1)(q_1q_2)^{2a}P_1^2 \quad \cdots\cdots (19)$$

at $R=3$

$$\Psi_{(k)}=(m-a)P_1^2q_2^2(q_1q_2)^{2a}+2(m-a-1)(q_1q_2)^{2a}P_1P_2q_1 \quad \cdots\cdots (20)$$

while at $R=4$

$$\Psi_{(k)}=(m-a-1)(q_1q_2)^{2a}(2P_1P_2q_1q_2+P_2^2q_1^2) \quad \cdots\cdots (21)$$

Here, $P_1=\frac{N_1}{2m}$, $P_2=\frac{N_2}{2m}$, $q_1=1-P_1$ and $q_2=1-P_2$.

Note: See the notes under the preceding form.

## 3. Exclusion of the influence of the gradient of the occupied-rate due to soaking time

Let us set that the occupied-rate of a hook in the $ith$ basket is set to be $(P+i\Delta P)$ for the purpose of representing the gradient and that $k=a(H+1)+R$. For

convenience' sake of explanation, the probability of occurrence in the two occupied-hooks spaced by $k$ hook-intervals each other and without any occupied inserted-hook is treated separately by the same manner as the preceding form. And the partial probabilities are represented in Table 9. And the formulae applicable to this type can be obtained by the same manner as the constructing-process of the preceding form; these are shown in the below:

at $R = 0$

$$\Psi_{(k)} = \sum_{i=1}^{m-a} \left\{ (P+i\Delta P)(P+\overline{i+a}\Delta P) \prod_{b=1}^{a-1} (q-\overline{i+b}\Delta P)^{H} \sum_{r=0}^{H-1} (q-i\Delta P)^{H-1-r} (q-\overline{i+a}\Delta P)^{r} \right\} \quad \cdots\cdots\cdots\cdots (22)$$

Table 9. Probability of occurrence in two occupied hooks spaced by $k$ hook-intervals each other and inserted no occupied hook, with particular reference to partial probabilities, when one starts to count $k$ from respective hooks in the $ith$ basket at respective $R$. (As a process of understanding easily the construction of the formulae of the interval analysis in which the influence of the gradient of the occupied rate due to soaking time is taken into consideration.)

| R | Order of hook in the $i$-$th$ basket starting to count $k$ | Order of hook spacing $k$ from it | Occupied probability of both terminal hooks | Consecutively unoccupied prob. of residual hooks in the $i$-$th$ basket | That of inserted baskets | That of hooks in the $(i+a)$-$th$ basket arranged earlier than a terminal |
|---|---|---|---|---|---|---|
| 0 | 1 | 1 | $(P+i\Delta P)\quad (P+\overline{i+a}\Delta P)$ | $(q-i\Delta P)^{a}$ | $\prod_{b=1}^{a-1}(q-\overline{i+b}\Delta P)^{4}$ | 1 |
| | 2 | 2 | $(P+i\Delta P)\quad (P+\overline{i+a}\Delta P)$ | $(q-i\Delta P)^{a}$ | $\prod_{b=1}^{a-1}(q-\overline{i+b}\Delta P)^{4}$ | $(q-\overline{i+a}\Delta P)$ |
| | 3 | 3 | $(P+i\Delta P)\quad (P+\overline{i+a}\Delta P)$ | $(q-i\Delta P)$ | $\prod_{b=1}^{a-1}(q-\overline{i+b}\Delta P)^{4}$ | $(q-\overline{i+a}\Delta P)^{2}$ |
| | 4 | 4 | $(P+i\Delta P)\quad (P+\overline{i+a}\Delta P)$ | 1 | $\prod_{b=1}^{a-1}(q-\overline{i+b}\Delta P)^{4}$ | $(q-\overline{i+a}\Delta P)^{3}$ |
| 1 | 1 | 2 | $(P+i\Delta P)\quad (P+\overline{i+a}\Delta P)$ | $(q-i\Delta P)^{a}$ | $\prod_{b=1}^{a-1}(q-\overline{i+b}\Delta P)^{4}$ | $(q-\overline{i+a}\Delta P)$ |
| | 2 | 3 | $(P+i\Delta P)\quad (P+\overline{i+a}\Delta P)$ | $(q-i\Delta P)^{a}$ | $\prod_{b=1}^{a-1}(q-\overline{i+b}\Delta P)^{4}$ | $(q-\overline{i+a}\Delta P)^{2}$ |
| | 3 | 4 | $(P+i\Delta P)\quad (P+\overline{i+a}\Delta P)$ | $(q-i\Delta P)$ | $\prod_{b=1}^{a-1}(q-\overline{i+b}\Delta P)^{4}$ | $(q-\overline{i+a}\Delta P)^{3}$ |
| | 4 | B | 0 | — | — | — |
| 2 | 1 | 3 | $(P+i\Delta P)\quad (P+\overline{i+a}\Delta P)$ | $(q-i\Delta P)^{a}$ | $\prod_{b=1}^{a-1}(q-\overline{i+b}\Delta P)^{4}$ | $(q-\overline{i+a}\Delta P)^{2}$ |
| | 2 | 4 | $(P+i\Delta P)\quad (P+\overline{i+a}\Delta P)$ | $(q-i\Delta P)^{a}$ | $\prod_{b=1}^{a-1}(q-\overline{i+b}\Delta P)^{4}$ | $(q-\overline{i+a}\Delta P)^{3}$ |
| | 3 | B | 0 | — | — | — |
| | 4 | 1 | $(P+i\Delta P)(P+\overline{i+a+1}\Delta P)$ | 1 | $\prod_{b=1}^{a}(q-\overline{i+b}\Delta P)^{4}$ | 1 |
| 3 | 1 | 4 | $(P+i\Delta P)\quad (P+\overline{i+a}\Delta P)$ | $(q-i\Delta P)^{a}$ | $\prod_{b=1}^{a-1}(q-\overline{i+b}\Delta P)^{4}$ | $(q-\overline{i+a}\Delta P)^{3}$ |
| | 2 | B | 0 | — | — | — |
| | 3 | 1 | $(P+i\Delta P)(P+\overline{i+a+1}\Delta P)$ | $(q-i\Delta P)$ | $\prod_{b=1}^{a}(q-\overline{i+b}\Delta P)^{4}$ | 1 |
| | 4 | 2 | $(P+i\Delta P)(P+\overline{i+a+1}\Delta P)$ | 1 | $\prod_{b=1}^{a}(q-\overline{i+b}\Delta P)^{4}$ | $(q-\overline{i+a+1}\Delta P)$ |
| 4 | 1 | B | 0 | — | — | — |
| | 2 | 1 | $(P+i\Delta P)(P+\overline{i+a+1}\Delta P)$ | $(q-i\Delta P)^{a}$ | $\prod_{b=1}^{a}(q-\overline{i+b}\Delta P)^{4}$ | 1 |
| | 3 | 2 | $(P+i\Delta P)(P+\overline{i+a+1}\Delta P)$ | $(q-i\Delta P)$ | $\prod_{b=1}^{a}(q-\overline{i+b}\Delta P)^{4}$ | $(q-\overline{i+a+1}\Delta P)$ |
| | 4 | 3 | $(P+i\Delta P)(P+\overline{i+a+1}\Delta P)$ | 1 | $\prod_{b=1}^{a}(q-\overline{i+b}\Delta P)^{4}$ | $(q-\overline{i+a+1}\Delta P)^{2}$ |

while at $R \neq 0$

$$\Psi_{(k)} = \sum_{i\ 1}^{m-a} \left\{ (P+i\Delta P)(P+\overline{i+a}\Delta P) \prod_{b=1}^{a-1} (q-\overline{i+b}\Delta P)^H \sum_{r=R}^{H-1} (q-i\Delta P)^{H+R-1-r} (q-\overline{i+a}\Delta P)^r \right\}$$
$$+ \sum_{i=1}^{m-a-1} \left\{ (P+i\Delta P)(P+i+a+1\Delta P) \prod_{b=1}^{a} (q-i+b\Delta P)^H \right.$$
$$\left. \sum_{r=0}^{R-2} (q-i\Delta P)^{R-2-r} (q-i+a+1\Delta P)^r \right\} \quad \cdots\cdots (23)$$

Here, $m$ is the number of gears connected into a row and $q=1-P$. When $H-1<R$, treat the former half of the Formula (23) as equal as 0; while when $R-2<0$, treat

| Product of these prob. | Range of $i$ capable of varying | |
|---|---|---|
| | Smallest | Largest |
| $(P+i\Delta P)(P+\overline{i+a}\Delta P)(q-i\Delta P)^a \prod_{b=1}^{a-1}(q-\overline{i+b}\Delta P)^A$ | 1 | (M−a) |
| $(P+i\Delta P)(P+\overline{i+a}\Delta P)(q-i\Delta P)^a(q-\overline{i+a}\Delta P) \prod_{b=1}^{a-1}(q-\overline{i+b}\Delta P)^A$ | 1 | (M−a) |
| $(P+i\Delta P)(P+\overline{i+a}\Delta P)(q-i\Delta P)(q-\overline{i+a}\Delta P)^a \prod_{b=1}^{a-1}(q-\overline{i+b}\Delta P)^A$ | 1 | (M−a) |
| $(P+i\Delta P)(P+\overline{i+a}\Delta P)(q-\overline{i+a}\Delta P)^a \prod_{b=1}^{a-1}(q-\overline{i+b}\Delta P)^A$ | 1 | (M−a) |
| $(P+i\Delta P)(P+\overline{i+a}\Delta P)(q-i\Delta P)^a(q-\overline{i+a}\Delta P) \prod_{b=1}^{a-1}(q-\overline{i+b}\Delta P)^A$ | 1 | (M−a) |
| $(P+i\Delta P)(P+\overline{i+a}\Delta P)(q-i\Delta P)^a(q-\overline{i+a}\Delta P)^a \prod_{b=1}^{a-1}(q-\overline{i+b}\Delta P)^A$ | 1 | (M−a) |
| | — | — |
| $(P+i\Delta P)(P+\overline{i+a}\Delta P)(q-i\Delta P)^a(q-\overline{i+a}\Delta P)^a \prod_{b=1}^{a-1}(q-\overline{i+b}\Delta P)^A$ | 1 | (M−a) |
| $(P+i\Delta P)(P+\overline{i+a}\Delta P)(q-i\Delta P)^a(q-\overline{i+a}\Delta P)^a \prod_{b=1}^{a-1}(q-\overline{i+b}\Delta P)^A$ | 1 | (M−a) |
| | — | — |
| $(P+i\Delta P)(P+\overline{i+a+1}\Delta P) \prod_{b=1}^{a}(q-\overline{i+b}\Delta P)^A$ | 1 | (M−a−1) |
| $(P+i\Delta P)(P+\overline{i+a}\Delta P)(q-i\Delta P)^a(q-\overline{i+a}\Delta P)^a \prod_{b=1}^{a-1}(q-\overline{i+b}\Delta P)^A$ | 1 | (M−a) |
| | — | — |
| $(P+i\Delta P)(P+\overline{i+a+1}\Delta P)(q-i\Delta P) \prod_{b=1}^{a}(q-\overline{i+b}\Delta P)^A$ | 1 | (M−a−1) |
| $(P+i\Delta P)(P+\overline{i+a+1}\Delta P)(q-\overline{i+a+1}\Delta P) \prod_{b=1}^{a}(q-\overline{i+b}\Delta P)^A$ | 1 | (M−a−1) |
| | — | — |
| $(P+i\Delta P)(P+\overline{i+a+1}\Delta P)(q-i\Delta P)^a \prod_{b=1}^{a}(q-\overline{i+b}\Delta P)^A$ | 1 | (M−a−1) |
| $(P+i\Delta P)(P+\overline{i+a+1}\Delta P)(q-i\Delta P)(q-\overline{i+a+1}\Delta P) \prod_{b=1}^{a}(q-\overline{i+b}\Delta P)^A$ | 1 | (M−a−1) |
| $(P+i\Delta P)(P+\overline{i+a+1}\Delta P)(q-\overline{i+a+1}\Delta P)^a \prod_{b=1}^{a}(q-\overline{i+b}\Delta P)^A$ | 1 | (M−a−1) |

the latter half of it as equal as 0.

Notes:

1) Besides the fact mentioned in the notes of the original form, attention should be paid to the following facts.

2) On account of the gradient, the estimation of the theoretical-values, especially those at longer $k$, becomes too troublesome to compute actually, which has much risk to introduce high computation-error.

3) Accordingly it is highly doubtful whether it is worthy to dare to compute actually with much effort such a value for fear of being uncertain. And it may be sufficient to take the magnitude of the influence of the gradient into consideration, deducing from the difference in the theoretical-value of this type at $k = 0$ from that of the original form, both of which take the same values as those of the spacing analysis of the corresponding types and are easily computable.

Table 10. Probability of occurrence in two occupied hooks spaced by $k$ hook-intervals each other and inserted no occupied hook, with particular reference to partial probabilities, when one starts to count $k$ from respective hooks in the *ith* basket at respective $R$. (As a process of understanding easily the construction of the formulae of the interval analysis, in which the influences of both factors are taken into consideration.)

| R | Order of hook in the $i$-*th* basket starting to count $k$ | Order of hook spacing $k$ From it | Occupied probability of both terminal hooks | Consecutively unoccupied prob. of residual hooks in the $i$-*th* basket | That of inserted baskets | That of hooks in the $(i+a)$-*th* basket arranged earlier than a terminal |
|---|---|---|---|---|---|---|
| 0 | 1 | 1 | $(P_1+\overline{1}\Delta P_1)(P_1+\overline{i+a}\Delta P_1)$ | $(q_1-\overline{1}\Delta P_1)(q_2-\overline{1}\Delta P_2)^2$ | $\prod_{b=1}^{a-1}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2$ | 1 |
| | 2 | 2 | $(P_2+\overline{1}\Delta P_2)(P_2+\overline{i+a}\Delta P_2)$ | $(q_1-\overline{1}\Delta P_1)(q_2-\overline{1}\Delta P_2)$ | $\prod_{b=1}^{a-1}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2$ | $(q_1-\overline{i+a}\Delta P_1)$ |
| | 3 | 3 | $(P_2+\overline{2}\Delta P_2)(P_2+\overline{i+a}\Delta P_2)$ | $(q_1-\overline{1}\Delta P_1)$ | $\prod_{b=1}^{a-1}(q_1+\overline{i+b}\Delta P_1)^2(q_2+\overline{i+b}\Delta P_2)^2$ | $(q_1-\overline{i+a}\Delta P_1)(q_2-\overline{i+a}\Delta P_2)$ |
| | 4 | 4 | $(P_1+\overline{i}\Delta P_1)(P_1+\overline{i+a}\Delta P_1)$ | 1 | $\prod_{b=1}^{a-1}(q_1+\overline{i+b}\Delta P_1)^2(q_2+\overline{i+b}\Delta P_2)^2$ | $(q_1-\overline{i+a}\Delta P_1)(q_2-\overline{i+a}\Delta P_2)^2$ |
| 1 | 1 | 2 | $(P_1+\overline{i}\Delta P_1)(P_2+\overline{i+a}\Delta P_2)$ | $(q_1-\overline{i}\Delta P_1)(q_2-\overline{i}\Delta P_2)^2$ | $\prod_{b=1}^{a-1}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2$ | $(q_1-\overline{i+a}\Delta P_1)$ |
| | 2 | 3 | $(P_2+\overline{i}\Delta P_2)(P_2+\overline{i+a}\Delta P_2)$ | $(q_1-\overline{i}\Delta P_1)(q_2-\overline{i}\Delta P_2)$ | $\prod_{b=1}^{a-1}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2$ | $(q_1-\overline{i+a}\Delta P_1)(q_2-\overline{i+a}\Delta P_2)$ |
| | 3 | 4 | $(P_2+\overline{i}\Delta P_2)(P_1+\overline{i+a}\Delta P_1)$ | $(q_1-\overline{i}\Delta P_1)$ | $\prod_{b=1}^{a-1}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2$ | $(q_1-\overline{i+a}\Delta P_1)(q_2-\overline{i+a}\Delta P_2)^2$ |
| | 4 | B | 0 | — | — | — |
| 2 | 1 | 3 | $(P_1+\overline{i}\Delta P_1)(P_1+\overline{i+a}\Delta P_1)$ | $(q_1-\overline{i}\Delta P_1)(q_2-\overline{i}\Delta P_2)^2$ | $\prod_{b=1}^{a-1}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2$ | $(q_1-\overline{i+a}\Delta P_1)(q_2-\overline{i+a}\Delta P_2)$ |
| | 2 | 1 | $(P_2+\overline{i}\Delta P_2)(P_1+\overline{i+a}\Delta P_1)$ | $(q_1-\overline{i}\Delta P_1)(q_2-\overline{i}\Delta P_2)$ | $\prod_{b=1}^{a-1}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2$ | $(q_1-\overline{i+a}\Delta P_1)(q_2-\overline{i+a}\Delta P_2)^2$ |
| | 3 | B | 0 | — | — | |
| | 4 | 1 | $(P_1+\overline{i}\Delta P_1)(P_1+\overline{i+a+1}\Delta P_1)$ | 1 | $\prod_{b=1}^{a}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2$ | 1 |
| 3 | 1 | 4 | $(P_1+\overline{i}\Delta P_1)(P_1+\overline{i+a}\Delta P_1)$ | $(q_1-\overline{i}\Delta P_1)(q_2-\overline{i}\Delta P_2)^2$ | $\prod_{b=1}^{a-1}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2$ | $(q_1-\overline{i+a}\Delta P_1)(q_2-\overline{i+a}\Delta P_2)^2$ |
| | 2 | B | 0 | — | — | |
| | 3 | 1 | $(P_2+\overline{i}\Delta P_2)(P_1+\overline{i+a+1}\Delta P_1)$ | $(q_1-\overline{i}\Delta P_1)$ | $\prod_{b=1}^{a}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2$ | 1 |
| | 4 | 2 | $(P_1+\overline{i}\Delta P_1)(P_2+\overline{i+a+1}\Delta P_2)$ | 1 | $\prod_{b=1}^{a}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2$ | $(q_1-\overline{i+a+1}\Delta P_1)$ |
| 4 | 1 | B | 0 | — | — | |
| | 2 | 1 | $(P_2+\overline{i}\Delta P_2)(P_1+\overline{i+a+1}\Delta P_1)$ | $(q_1-\overline{i}\Delta P_1)(q_2-\overline{i}\Delta P_2)$ | $\prod_{b=1}^{a}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2$ | 1 |
| | 3 | 2 | $(P_2+\overline{i}\Delta P_2)(P_2+\overline{i+a+1}\Delta P_2)$ | $(q_1-\overline{i}\Delta P_1)$ | $\prod_{b=1}^{a}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2$ | $(q_1-\overline{i+a+1}\Delta P_1)$ |
| | 4 | 3 | $(P_1+\overline{i}\Delta P_1)(P_2+\overline{i+a+1}\Delta P_2)$ | 1 | $\prod_{b=1}^{a}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2$ | $(q_1-\overline{i+a+1}\Delta P_1)(q_2-\overline{i+a+1}\Delta P_2)$ |

## 4. Exclusion of the influence of both factors, the gradient of occupied-rate due to that of soaking time and the difference in the occupied-rate due to the depth levels of the hooks

The formulae applicable to this most complicated condition are obtained from the original form by double transformation —— first, by the same manner as that of Formulae (15) and (16) into (17)～(21) for the purpose of excluding the influence of the difference in the occupied-rate due to that of fishing depth of hooks, then by the same manner as that of Formulae (15) and (16) into (22) and (23) in order to exclude the influence of the gradient of the occupied-rate due to soaking time. Consequently, the formulae are obliged to take the different forms with the difference in the number of hooks attaching to each basket. And only those applicable to the gears constituted of a connected series of baskets attaching to four hooks a basket are illustrated in the below, as an example.

| Product of these prob. | Range of $i$ capable of varying | |
|---|---|---|
| | Smallest | Largest |
| $(P_1+i\Delta P_1)(P_1+\overline{i+a}\Delta P_1)(q_1-i\Delta P_1)(q_2-i\Delta P_2)^2\prod_{b=1}^{a-1}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2$ | 1 | (M−a) |
| $(P_2+i\Delta P_2)(P_2+\overline{i+a}\Delta P_2)(q_1-i\Delta P_1)(q_2-i\Delta P_2)(q_1-\overline{i+a}\Delta P_1)\prod_{b=1}^{a-1}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2$ | 1 | (M−a) |
| $(P_2+i\Delta P_2)(P_2+\overline{i+a}\Delta P_2)(q_1-i\Delta P_1)(q_1-\overline{i+a}\Delta P_1)(q_2-\overline{i+a}\Delta P_2)\prod_{b=1}^{a-1}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2$ | 1 | (M−a) |
| $(P_1+i\Delta P_1)(P_1+\overline{i+a}\Delta P_1)(q_1-\overline{i+a}\Delta P_1)(q_2-\overline{i+a}\Delta P_2)^2\prod_{b=1}^{a-1}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2$ | 1 | (M−a) |
| $(P_1+i\Delta P_1)(P_2+\overline{i+a}\Delta P_2)(q_1-i\Delta P_1)(q_2-i\Delta q_2)^2(q_1-\overline{i+a}\Delta P_1)\prod_{b=1}^{a-1}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2$ | 1 | (M−a) |
| $(P_2+i\Delta P_2)(P_2+\overline{i+a}\Delta P_2)(q_1-i\Delta P_1)(q_2-i\Delta q_2)(q_1-\overline{i+a}\Delta P_1)(q_2-\overline{i+a}\Delta P_2)\prod_{b=1}^{a-1}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2$ | 1 | (M−a) |
| $(P_2+i\Delta P_2)(P_1+\overline{i+a}\Delta P_1)(q_1-i\Delta P_1)(q_1-\overline{i+a}\Delta P_1)(q_2-\overline{i+a}\Delta P_2)^2\prod_{b=1}^{a-1}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2$ | 1 | (M−a) |
| | | — |
| $(P_1+i\Delta P_1)(P_2+\overline{i+a}\Delta P_2)(q_1-i\Delta P_1)(q_2-i\Delta P_2)^2(q_1-\overline{i+a}\Delta P_1)(q_2-i+a\Delta P_2)\prod_{b=1}^{a-1}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2$ | 1 | (M−a) |
| $(P_2+i\Delta P_2)(P_1+\overline{i+a}\Delta P_1)(q_1-i\Delta P_1)(q_2-i\Delta P_2)(q_1-\overline{i+a}\Delta P_1)(q_2-\overline{i+a}\Delta P_2)^2\prod_{b=1}^{a-1}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2$ | 1 | (M−a) |
| | — | — |
| $(P_1+i\Delta P_1)(P_1+\overline{i+a+1}\Delta P_1)\prod_{b=1}^{a}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2$ | 1 | (M−a−1) |
| $(P_1+i\Delta P_1)(P_1+\overline{i+a}\Delta P_1)(q_1-i\Delta P_1)(q_2-i\Delta P_2)^2(q_1-\overline{i+a}\Delta P_1)(q_2-\overline{i+a}\Delta P_2)^2\prod_{b=1}^{a-1}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2$ | 1 | (M−a) |
| | — | — |
| $(P_2+i\Delta P_2)(P_1+\overline{i+a+1}\Delta P_1)(q_1-i\Delta P_1)\prod_{b=1}^{a}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2$ | 1 | (M−a−1) |
| $(P_1+i\Delta P_1)(P_2+\overline{i+a+1}\Delta P_2)(q_1-\overline{i+a+1}\Delta P_1)\prod_{b=1}^{a}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2$ | 1 | (M−a−1) |
| | — | — |
| $(P_2+i\Delta P_2)(P_1+\overline{i+a+1}\Delta P_1)(q_1-i\Delta P_1)(q_2-i\Delta P_2)\prod_{b=1}^{a}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2$ | 1 | (M−a−1) |
| $(P_2+i\Delta P_2)(P_2+\overline{i+a+1}\Delta P_2)(q_1-i\Delta P_1)(q_1-\overline{i+a+1}\Delta P_1)\prod_{b=1}^{a}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2$ | 1 | (M−a−1) |
| $(P_1+i\Delta P_1)(P_2+\overline{i+a+1}\Delta P_2)(q_1-\overline{i+a+1}\Delta P_1)(q_2-\overline{i+a+1}\Delta P_2)\prod_{b=1}^{a}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2$ | 1 | (M−a−1) |

In order to represent the gradient of the occupied-rate of the hooks at respective depth levels, the occupied-rates of respective hooks are set to take the values shown in Table 5 (c) and that $q_1=1-P_1$ and $q_2=1-P_2$. Then, the total number of the gears connected into a row is set to be $m$ and the interval $k$ is represented as $a(4+1)+R$. The partial probabilities——the occupied probability of the two hooks spaced by a width as long as $k$ hook-intervals each other, the unoccupied probability of the hooks in the $ith$ basket located in the range latter than the hook starting to count $k$, the successively unoccupied probability of the inserted baskets and the unoccupied probability of the hooks in the $(i+a)th$ or in the $(i+a+1)th$ basket coming earlier than the ending hook to count $k$ ——, when one starts to count $k$ from respective hooks in the $ith$ basket at respective $R$, are listed in Table 10. And the probability of occurrence in the two occupied-hooks spaced by $k$ hook-intervals each other and inserted no occupied-hook, starting to count $k$ from respective hooks in the $ith$ basket at respective $R$ is the product of the four probabilities arranged horizontally in Table 10. But the expectant number of respective cases is computable by summing the respective products in which "$i$" is increased step by step from 1 to $(m-a)$ or to $(m-a-1)$. And the expectant number at respective $R$ is obtained by summing from these sums started to count $k$ from the first hook in the basket to those from the hindmost hook in it, which are shown in the below:

at $R=0$

$$
\begin{aligned}
\Psi_{(k)}=&\sum_{i=1}^{m-a}\Big\{(P_1+i\Delta P_1)(P_1+\overline{i+a}\Delta P_1)(q_1-i\Delta P_1)(q_2-i\Delta P_2)^2\\
&\prod_{b=1}^{a-1}(q_1-\overline{i+b}\Delta P_1)^2(q_2-i+b\Delta P_2)^2\Big\}\\
&+\sum_{i=1}^{m-a}\Big\{(P_2+i\Delta P_2)(P_2+\overline{i+a}\Delta P_2)(q_1-i\Delta P_1)(q_2-i\Delta P_2)(q_1-i+a\Delta P_1)\\
&\prod_{b=1}^{a-1}(q_1-i+b\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2\Big\}\\
&+\sum_{i=1}^{m-a}\Big\{(P_2+i\Delta P_2)(P_2+\overline{i+a}\Delta P_2)(q_1-i\Delta P_1)(q_1-i+a\Delta P_1)(q_2-\overline{i+a}\Delta P_2)\\
&\prod_{b=1}^{a-1}(q_1-i+b\Delta P_1)^2(q_2-i+b\Delta P_2)^2\Big\}\\
&+\sum_{i=1}^{m-a}\Big\{(P_1-i\Delta P_1)(P_1+i+a\Delta P_1)(q_1-i+a\Delta P_1)(q_2-i-a\Delta P_2)^2\\
&\prod_{b=1}^{a-1}(q_1-i+b\Delta P_1)^2(q_2-i+b\Delta P_2)^2\Big\}\qquad\cdots\cdots(24)
\end{aligned}
$$

at $R=1$

$$\begin{aligned}\Psi_{(k)}=&\sum_{i=1}^{m-a}\Big\{(P_1+i\Delta P_1)(P_2+\overline{i+a}\Delta P_2)(q_1-i\Delta P_1)(q_2-i\Delta P_2)^2(q_1-\overline{i+a}\Delta P_1)\\&\prod_{b=1}^{a-1}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2\Big\}\\&+\sum_{i=1}^{m-a}\Big\{(P_2+i\Delta P)(P_2+\overline{i+a}\Delta P_2)(q_1-i\Delta P_1)(q_2-i\Delta P_2)(q_1-\overline{i+a}\Delta P_1)(q_2-\overline{i+a}\Delta P_2)\\&\prod_{b=1}^{a-1}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2\Big\}\\&+\sum_{i=1}^{m-a}\Big\{(P_2+i\Delta P_2)(P_1+\overline{i+a}\Delta P_1)(q_1-i\Delta P_1)(q_1-\overline{i+a}\Delta P_1)(q_2-\overline{i+a}\Delta P_2)^2\\&\prod_{b=1}^{a-1}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2\Big\}\cdots\cdots(25)\end{aligned}$$

at $R=2$

$$\begin{aligned}\Psi_{(k)}=&\sum_{i=1}^{m-a}\Big\{(P_1+i\Delta P_1)(P_2+\overline{i+a}\Delta P_2)(q_1-i\Delta P_1)(q_2-i\Delta P_2)^2(q_1-\overline{i+a}\Delta P_1)(q_2-\overline{i+a}\Delta P_2)\\&\prod_{b=1}^{a-1}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2\Big\}\\&+\sum_{i=1}^{m-a}\Big\{(P_2+i\Delta P_2)(P_1+\overline{i+a}\Delta P_1)(q_1-i\Delta P_1)(q_2-i\Delta P_2)(q_1-\overline{i+a}\Delta P_1)(q_2-\overline{i+a}\Delta P_2)^2\\&\prod_{b=1}^{a-1}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2\Big\}\\&+\sum_{i=1}^{m-a-1}\Big\{(P_1+i\Delta P_1)(P_1+\overline{i+a+1}\Delta P_1)\prod_{b=1}^{a}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2\Big\}\cdots(26)\end{aligned}$$

at $R=3$

$$\begin{aligned}\Psi_{(k)}=&\sum_{i=1}^{m-a}\Big\{(P_1+i\Delta P_1)(P_1+\overline{i+a}\Delta P_1)(q_1-i\Delta P_1)(q_2-i\Delta P_2)^2(q_1-\overline{i+a}\Delta P_1)(q_2-\overline{i+a}\Delta P_2)^2\\&\prod_{b=1}^{a-1}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2\Big\}\\&+\sum_{i\ \ 1}^{m-a-1}\Big\{(P_2+i\Delta P_2)(P_1+\overline{i+a+1}\Delta P_1)(q_1-i\Delta P_1)\\&\prod_{b=1}^{a}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2\Big\}\end{aligned}$$

$$+\sum_{i=1}^{m-a-1}\left\{(P_1+i\Delta P_1)(P_2+\overline{i+a+1}\Delta P_2)(q_1-\overline{i+a+1}\Delta P_1)\right.$$
$$\left.\prod_{b=1}^{a}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2\right\} \quad \cdots\cdots (27)$$

while at $R=4$

$$W_{(k)}=\sum_{i=1}^{m-a-1}\left\{(P_2+i\Delta P_2)(P_1+\overline{i+a+1}\Delta P_1)(q_1-i\Delta P_1)(q_2-i\Delta P_2)\right.$$
$$\left.\prod_{b=1}^{a}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2\right\}$$
$$+\sum_{i=1}^{m-a-1}\left\{(P_2+i\Delta P_2)(P_2+\overline{i+a+1}\Delta P_2)(q_1-i\Delta P_1)(q_1-\overline{i+a+1}\Delta P_1)\right.$$
$$\left.\prod_{b=1}^{a}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2\right\}$$
$$+\sum_{i=1}^{m-a-1}\left\{(P_1+i\Delta P_1)(P_2+\overline{i+a+1}\Delta P_2)(q_1-\overline{i+a+1}\Delta P_1)(q_2-\overline{i+a+1}\Delta P_2)\right.$$
$$\left.\prod_{b=1}^{a}(q_1-\overline{i+b}\Delta P_1)^2(q_2-\overline{i+b}\Delta P_2)^2\right\} \quad \cdots\cdots (28)$$

Note : See the notes under the preceding forms.

## Results of the Interval Analysis

Far sharper decrease of the observed-values with increase in $k$ is introduced into the interval analysis by taking the fact whether the interval has any occupied inserted-hook or not into consideration; this makes it impossible to be tried this method on the analysis of the examples in which the individuals are not so densely hooked, even if some of them are so dense as to be available for the spacing analysis. Therefore, of course, it is the important subjects not only to know the distribution patterns of respective species but also to find out the difference in the patterns with species. But the actual analyses are tried only on the examples of the yellow-fin tuna, because I am afraid that the number of the hooked-individuals of the other species than the yellow-fin tuna by each row is too scarce to obtain the results somewhat rid of the influence of accidental error; while even the theoretical-values of the original form and the excluded form of the influence of the difference in the occupied-rates of the hooks located at the different depth levels in such examples of high occupied-rates as those of the yellow-fin tuna have much risk to bear some computation error, because the unoccupied-rates of the inserted-hooks are introduced into the form of product.

Moreover, for the forms in which the influence of the gradient of the occupied-rate is excluded, especially for the values at longer $k$, the treatment of the unoccupied-rates of the inserted-hooks got too complicated, which not only makes it too troublesome to compute the theoretical-values but also has far more risk to introduce high computation-error into them. Accordingly, for the influence of the gradient no further consideration is given except that some attention is paid to the magnitude of the influence of this fact comparing the unexcluded value at $k = 1$ with the corresponding excluded one. Moreover, against the fact that the structure extending to wide range can be analyzed by the spacing analysis in which a little long unit-length is adopted, the difference in the treatment of the inserted-hooks of the interval method from that of the spacing one makes it impossble to give any consideration upon the structures extending to a wide range however the unit-length may be elongated. This interval method is thought to prove its merits only when this method is adopted as a preliminary step to the arrangement analysis which will be mentioned in the next part. Therefore, no description of the results of the interval analysis except the brief notes on some characteristics of the deviation in the observed-values and the difference in them from the estimated ones, are illustrated; and the meanings of respective descriptions will be easily understood from the descriptions of the results of the arrangement analysis.

## 1. Exposition of particular example

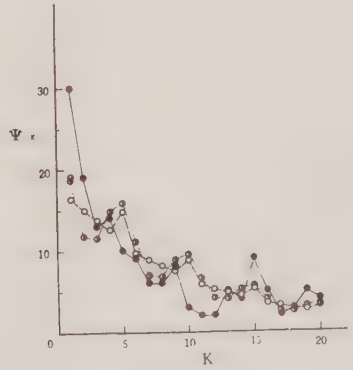



Fig. 38. The deviation of the observed numbers of the individuals spaced by respective widths from next individuals, in contrast with that of the theoretically estimated ones (Example Y 1 ).

Notes (common to Figs. 38～49) :

Solid circles represent the observed numbers ; the open ones do the theoretical ones computed from Formulae (15) & (16), in which the occupied-rates of all the hooks are set to be the same ; the marks, ◑, do those from Formulae (17)～(21), in which the influence of the periodicity of occupied-rate due to the fishing depths of hooks is taken into consideration ; while the mark, ◒, does that from Formula (25), in which the influences of both the gradient and periodicity of occupied-rate are taken into consideration.

**Example Y 1** : 1) The influence of the gradient of the occupied-rate is negligibly weak. 2) Rather strong contagiousness is observable within the width of two hook-intervals. 3) The observed-values in the range $4 \leqq k \leqq 14$ take continuously lower values than the estimated ones. 4) The second peak of the observed-values is at $k=15$.

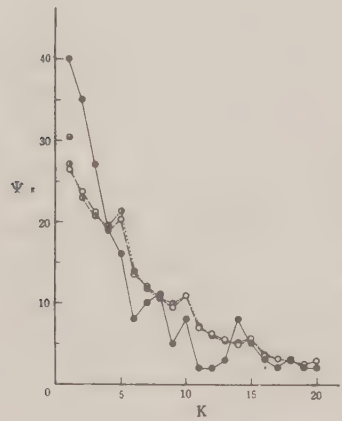



Fig. 39. The deviation of the observed numbers of the individuals spaced by respective widths from next individuals, in contrast with that of the theoretically estimated ones (Example Y 2 ).

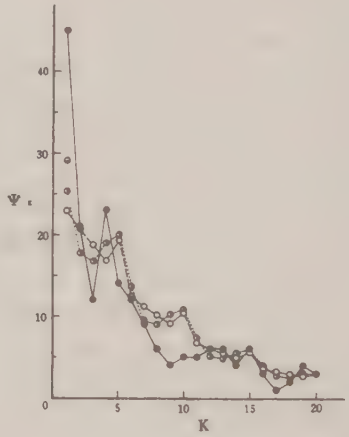



Fig. 40. The deviation of the observed numbers of the individuals spaced by respective widths from next individuals, in contrast with that of the theoretically estimated ones (Example Y 3 ).

**Example Y 2**: 1) The influence of the gradient raises 10 % of the estimated-values, while the difference in the occupied-rates of the hooks at the different depth levels is not so strongly influential. 2) The strong contagiousness is observable within the width of three hook-intervals. 3) But the observed-values of the rests of it are continuously lower than the estimated ones, except that at $k = 14$.

**Example Y 3**: 1) Both the gradient and the difference in the occupied-rate due to fishing depths influence strongly on the values. 2) The strong contagiousness is admitted as long as one hook-interval width. 3) The second peak of the observed-values is at $k=4$. 4) The observed-values in the range $5 \leqq k \leqq 12$ continuously take lower values than the estimated ones. But those of the rests of them do not differ from the estimated ones too much.

**Example Y 4**: 1) The difference in the occupied rates due to fishing depths of hooks is significantly influential, while the influence of the gradient is negligible. 2) The strong contagiousness is observable within the width of three hook-intervals, especially strong at $k = 1$ and 3; while for the rests of it, no high observed-value is found except that at $k = 20$.

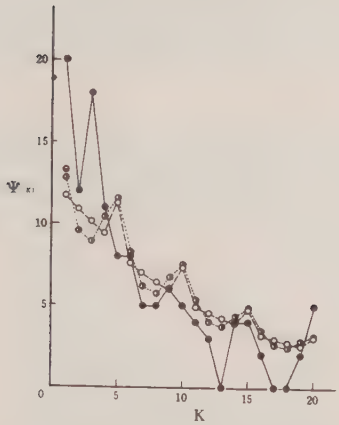



Fig. 41. The deviation of the observed numbers of the individuals spaced by respective widths from next individuals, in contrast with that of the theoretically estimated ones (Example Y 4 ).

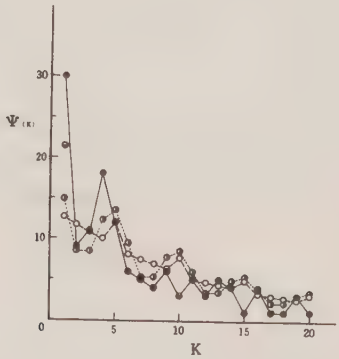



Fig. 42. The deviation of the observed numbers of the individuals spaced by respective widths from next individuals, in contrast with that of the theoretically estimated ones (Example Y 5 ).

**Example Y 5**: 1) Both factors are strongly influential, of which the gradient is severer. 2) Contagiousness is admitted only as long as one hook-interval width, although it is extremely strong. 3) No high observed-value is found in the parts $k$ of which is longer than a basket width.

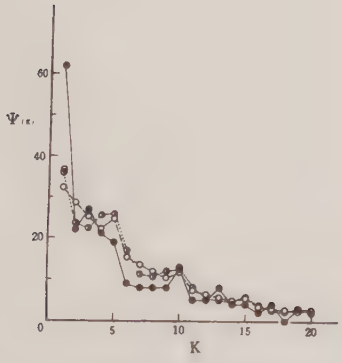



Fig. 43. The deviation of the observed numbers of the individuals spaced by respective widths from next individuals, in contrast with that of the theoretically estimated ones (Example Y 6 ).

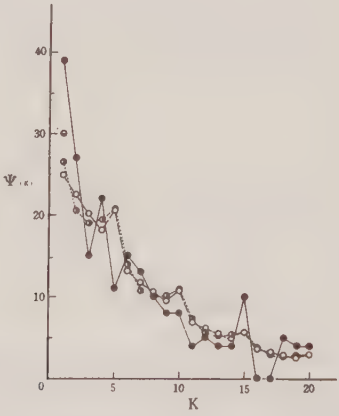



Fig. 44. The deviation of the observed numbers of the individuals spaced by respective widths from next individuals, in contrast with that of the theoretically estimated ones (Example Y 7 ).

**Example Y 6**: 1) The influence of the gradient of the occupied-rate is negligibly

weak, contrary to the fact that the difference in the occupied-rates due to fishing depths of hooks is affecting strongly on the values. 2) No contagious structure is suspected else than the fact that the observed-values at $k = 1$, 3 and 13 seem to be slightly higher than the estimated ones.

**Example Y 7**: 1) The gradient of the occupied-rate influences strongly on the values. 2) Rather strong contagiousness is admitted within two hook-intervals. 3) The observed-values in the rests of it slightly deviate around the estimated ones. But the observed-value at $k = 15$ seems to be higher than the estimated one.

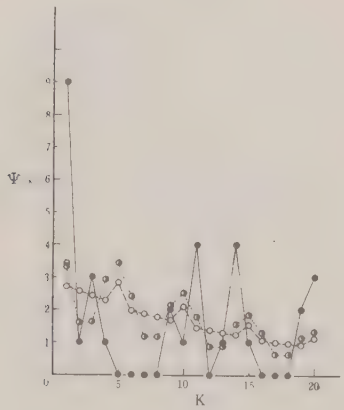



Fig. 45. The deviation of the observed numbers of the individuals spaced by respective widths from next individuals, in contrast with that of the theoretically estimated ones (Example Y 8).

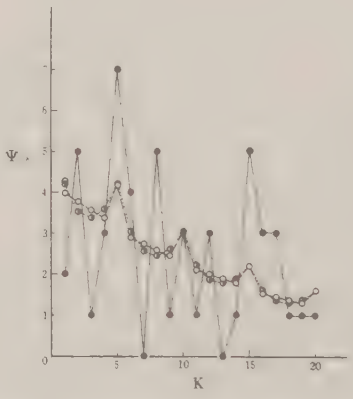



Fig. 46. The deviation of the observed numbers of the individuals spaced by respective widths from next individuals, in contrast with that of the theoretically estimated ones (Example Y 9).

**Example Y 8**: 1) The poor total-catch causes the low estimated-values and the high probability to introduce accidental error into the observed-values. 2) The difference in the occupied-rates of the hooks located at the different depth levels is strongly influential, while the influence of the gradient is negligible. 3) The expectant severe influence of accidental error allows us to tell nothing but the fact that the strong contagiousness is admitted within one hook-interval width.

**Example Y 9**: 1) The poor total-catch has much risk to introduce severe influence of accidental error into the observed-values. 2) Not only the influence of the gradient but also that of the difference in the occupied-rates are negligibly weak. 3) The observed-values within a short interval seem to allude to a self-spacing pattern, while whether we can give any significance to it or not is highly doubtful.

**Example Y 10**: 1) It is one of the characteristics of the distribution pattern of this example that, if the small deviations are neglected, the observed-values exceed continuously the estimated ones rather longer hook-intervals (to $k = 8$), which suggests

that even the pair of individuals hooked spaced by the width so long as to $1\frac{1}{2}$ basket can be regarded as contagious.

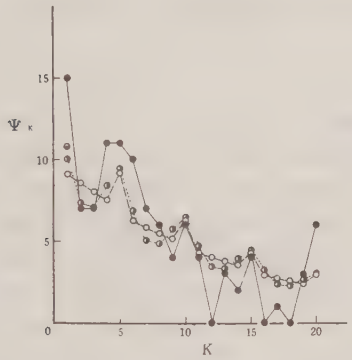



Fig. 47. The deviation of the observed numbers of the individuals spaced by respective widths from next individuals, in contrast with that of the theoretically estimated ones (Example Y 10).

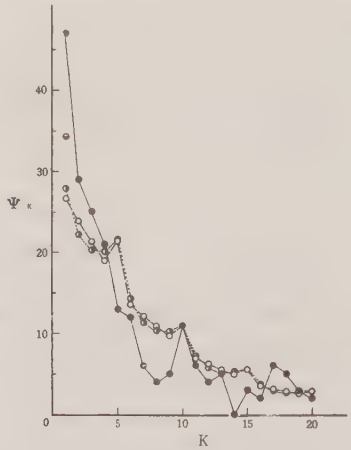



Fig. 48. The deviation of the observed numbers of the individuals spaced by respective widths from next individuals, in contrast with that of the theoretically estimated ones (Example Y 11).

**Example Y 11**: 1) The influence of the gradient is rather strong; while that of the difference in the occupied-rate due to the fishing depth of the hooks is negligibly weak. 2) Even if the influence of the gradient is taken into consideration, the observed-values deviate in showing rather long periodicity. 3) The observed-values within three hook-intervals exceed the theoretical-values, of which that at $k = 1$ is the most predominant. 4) Some significance may well be given to the high observed-values at $k = 17 \sim 19$.

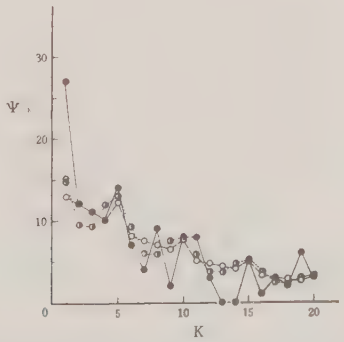



Fig. 49. The deviation of the observed numbers of the individuals spaced by respective widths from next individuals, in contrast with that of the theoretically estimated ones (Example Y 12).

**Example Y 12**: 1) The difference in the occupied-rates influences strongly on the values, while contagiousness the influence of the gradient is almost negligible. 2) Nothing but strong contagiousness at $k = 1$ is alluded to.

## 2. Comparison of the results of the spacing analysis with those of the interval one

Before closing this part, some attention should be paid to what kinds of differences between the results are caused by the difference in the treatment of the inserted hooks. Moreover, it is far more important to give some consideration upon what structures in the pattern projected along long-line are suggested from these differences. Therefore, the results of the interval analysis are compared with those of the spacing one example by example and the deduced facts will be briefly described in the below.

**Example Y 1**: The high observed-values at $k = 1, 2, 15, 16, 19$ and 20 are in common with both analyses; while for the differences in the results of both analyses, it becomes clear that the high observed-values at $3 \leqq k \leqq 5$ in the spacing analysis are chiefly due to the fact that the numbers of the intervals inserted no occupied-hook and covering respective widths are not so many while the intervals inserted some occupied ones —— constituted of two or more successively arranged intervals of one or two hook-interval width —— are more frequently observable than expected.

**Example Y 2**: The results of the spacing analysis and the interval one, if dare to say, tell us superficially considerably different patterns, and this fact may chiefly be due to the following reasons: the continuously high observed-values of the spacing analysis within three hook-intervals may be thought as if to allude to the same results as those of the interval analysis. Yet, for even these high observed-values, the more careful examination reveals that the intervals inserted no occupied-hook and covering respective widths are, of course, a little more frequently observable, but such fact surely contributes to emphasizing the high observed-values in the spacing analysis that two or more intervals, each covering one or two hook-intervals arranged successively and covering within three hook-intervals, are also more frequently observable than expected. And, this second reason —— two or more intervals of shorter width arranged successively are far more frequently observable than expected—— is more heavily influential at $k = 4, 5, 8$ and from 10 to 18, consequently, the observed-values at these $k$ in the spacing analysis become higher than expected, overcoming the low observed-values in the interval analysis, which are each as equal as the number of the intervals of respective lengths and inserted no occupied-hook.

**Example Y 3**: The pattern deducible from the results of both analyses seems to be somewhat different from each other. Yet, if we suppose as follows, the pattern alluded to from the results of the spacing analysis can be expected from the results

of the interval analysis: the intervals of one hook-interval width are far more frequently observable than expected; accordingly the number of the intervals of a certain length ($k'$) constituted of some intervals of one hook-interval wide and of some ones shorter than this length ($k'$) are expected to be far more frequently observable; and the deficiency of the intervals covering the width longer than one hook-interval, or —— if neglecting the small deviations —— longer than a basket and inserted no occupied-hook is complemented and the observed-values in the spacing analysis come to deviate around the estimated ones, just the same pattern as the results of the spacing analysis.

**Example Y 4** : The differences between the results of both analyses, except those observed at $k = 4$ and 5, are not so significant and can be easily explained by the same reason mentioned already in the preceding example. Moreover, even the differences observable at $k = 4$ and 5 are also easily recognizable by the same reason —— *i.e.*, even if the number of the intervals each covering 4 or 5 hook-intervals may be observed as frequently as or somewhat less frequently than that expected in the chance distribution, the intervals covering as long as or shorter than three hook-intervals occur more frequently, consequently, the numbers of the intervals covering 4 or 5 hook-intervals inserted any occupied-hook ( = constituted of some successively arranged intervals) must be also far more frequently observable, which result to show high observed-values in the spacing analysis, because by which ways the intervals of 4 or 5 hook-interval width may be sectioned, most of the compornents are as long as or shorter than three hook-intervals.

**Example Y 5** : The gradient influences rather severely on the values and its influence raises ⅓ of the estimated-value at $k = 1$. And if the series of the theoretical-values in the interval analysis at longer $k$ might be computed, I am afraid that considerably high computation-error may be introduced. Accordingly, exactly speaking, no probable suggestion can be found out for the problem that the estimated-values in the interval analysis at longer $k$ should be corrected how largely, or, if dare to say, even for the problem whether they should be increased or decreased. Furthermore, not only the estimated-values in which the influence of the gradient is not excluded but also the observed ones of the interval analysis in the range $k \geqq 10$ do not reach five; accordingly the results are thought to be strongly influenced by accidental error. Therefore, no description is given to the difference between the patterns deduced from the results of the spacing analysis and those of the interval one but somewhat similar pattern may be deducible from both methods.

**Example Y 6** : In such example of high occupied-rate as this, the theoretical-values of the interval analysis decrease rapidly (this means that the absolute difference itself of the theoretical-values at shorter interval from longer one is the larger, when the occupied-rate $P$ is the higher, although the rate of decrease per increase in hook-interval is nearly as equal as $q$ which is the smaller). Thus, the large difference

between the theoretical-values in the interval analysis from those in the spacing one at longer $k$ is expected, because the theoretical-values in the spacing analysis do not decrease so sharply. And the intervals in the spacing analysis corresponding to this difference are those with occupied-hook, in other words, those constituted of some shorter intervals arranged successively. Therefore, the difference in the treatment of the inserted occupied-hook in the interval analysis from that in the spacing one is severely influential in such example of high occupied-rate as this.

For the results of the interval analysis of this example, the observed-value at one hook-interval width exceeds largely the estimated one, while those of the rests of it are rather lower than the estimated ones. And the observed-values in the spacing analysis seem to be strongly affected by the predominance of the intervals of one hook-interval wide, consequently, such results as represented in the spacing analysis can be easily presumed, *i.e.*, the observed-values in the spacing analysis at $k \leqq 13$ exceed continuously the estimated ones, and those in the range from $14 \leqq k \leqq 20$ are increased into the values as high as the estimated ones.

**Example Y 7** : The intervals covering one or two hook-interval width are far more frequently observable, which slightly raises all the observed-values in the spacing analysis. This fact considered together, most of the deviations of the observed-values in the spacing analysis can be easily recognized, but the slightly high value at $k = 11$ and the conspicuously low value at $k = 12$ may be thought to be due to some specific structures or accidental error because no symptom suggesting the possibility in the occurrence of them can be found out from the interval analysis.

**Example Y 8** : All the estimated-values in the interval analysis do not reach five, because of the scarcity of the hooked-individuals. Accordingly, I am afraid of the fact that considerably severe influence of accidental error is introduced. And also the low occupied-rate results in the small difference in the observed-values as well as in the estimated ones between the spacing analysis and the interval one, as actually obtained.

**Example Y 9** : Despite of the low observed-values and the estimated ones which have much risk to introduce severe influence of accidental error, quite the same pattern is suggested from both analyses.

**Example Y 10** : Although some differences seem to be observable between the results of both analyses at the parts where $k \geqq 10$, we can not give any significance upon them, because both the observed-values and the estimated ones of the interval analysis in the range from $k = 10$ to 20 are not so high enough as to be deducible any fact excerting on not so severe influence of accidental error. Accordingly, it may well be considered that considerably well coincident pattern is suggested from the results of both analyses, against the fact that the intervals covering one hook-interval width are observable 150 % as frequently as expected, which is probable to increase all the observed-values in the spacing analysis.

**Example Y 11** : Pay heed to the fact that the same special attention as Example Y 5 (strong gradient) and as Example Y 6 (high occupied-rate) should be paid to the comparison of the results of both analyses. Then the apparent differences in the results between both analyses come to be recognizable. That is to say, the continuously high observed-values within three hook-intervals are in common with both analyses. But the observed-value at $k = 4$ in the spacing analysis largely exceeds the estimated one against the fact that the observed one in the interval analysis, if taking the influence of the gradient into consideration, is a little lower than the estimated one. And the higher value at $k = 5$ than the estimated one is observable in the spacing analysis, despite of the fact that the observed one in the interval analysis is far lower than the estimated one. And the similar but enfeebled differences can be observed at $k = 6$ and 7; while for the range from $k = 8$ to 20, the tendency to the difference in the observed-values between both analyses becomes weaker and weaker with increase in $k$ and the deviations of the observed-values in both analyses tend to show the features capable of regarding as the same, if accidental error due to the low observed-values and the estimated ones are taken into consideration. These phenomena are thought to be due to the fact that the most of the compornent-intervals constituting not so long intervals are those covering one or two hook-interval width and the predominance of them affects conspicuously on the occurrence in the intervals of not so long width, but the proportion of such shorter intervals to total compornent-intervals decreases with increase in $k$ and the predominance of shorter ones becomes less influential.

**Example Y 12** : The deviation of five hook-interval periodicity of the observed-values in the spacing analysis is rather conspicuously represented, against the fact that no clear symptom suggesting the possibility in the occurrence of it is observable in the results of the interval analysis. Accordingly, this may be thought to be due to the specific structure. Besides this, more detailed examination suggests the presence of some other differences. For examples, the observed-value in the spacing analysis at $k = 3$ is not so high as to be supposed from the predominance in the observed-value in the interval analysis at $k = 1$; at $k = 7$, the observed-value in the spacing analysis is a little higher than the estimated one but the observed-value in the interval analysis is lower than the estimated one; while at $k = 8$, the observed-value in the spacing analysis is lower than the estimated one although the observed-value in the interval analysis exceeds the estimated one; and at $k = 14$, the observed-value in the spacing analysis exceeds the estimated one against the fact that the observed-value in the interval analysis is lower than the estimated one.

**Summarized results of the comparison**

The observed-values and the estimated ones in the interval analysis do not contain any interval with any occupied-hook. Accordingly, the difference in the values of the spacing analysis from the interval one represents theoretically the number of the intervals of respective lengths with any occupied-hook. Accordingly, the difference

in the observed-value from the estimated one in the spacing analysis at any $k_1$ represents the differences in the interval analysis in the range $k \leqq k_1$ cumulatively. And, the most of the apparent differences in the results in the spacing analysis from those in the interval one are easily explained from the above-mentioned reasons, but only a little of them can do so, which is thought to be based on the specific structure.

# Part Ⅲ Arrangement Analysis

## Method of Analysis

Adding the interval analysis makes the distribution pattern analyzable more easily and clearly overcoming the influence of the fact whether any of the inserted-hook in the interval under consideration is occupied or not; but we can certify from the results of this analysis only the fact that the intervals how longly covering are more frequently observable than expected from the chance distribution. But there remains another factor untouched —— this is the manner of the arrangement of the intervals covering respective widths. And if we want to find out any clear conclusion of the distribution pattern, the interval analysis is not sufficient, but the following series of analysis should be added, which is, for convenience' sake, called "arrangement analysis".

The school commonly recognized may indicate the aggregation of the individuals having some psychological interrelations one another. But, for the population certified by the distribution pattern of the hooked-individuals along long-line, it is very hard to certify the presence of any psychological relation, because the individuals are swimming in too deep layer and scattering about too wide space. And even if dare to know, nothing else than static characteristics such as body length, body weight, stomach contents, radioactive contamination degree *etc.* is the factor actually applicable. But they can not effectively tell us the possibility of the presence or absence of the psychological relation nor can be the proof capable of supporting its presence. Thus, there is no factor more suitable for finding out the feature of school-formation than the distribution of the hooked-individuals along long-line. Therefore, I wish to, hereafter, analyze the distribution pattern of the hooked-individuals along longline as in detail as possible; then by evolving from the results of the analyses, as many suggestions about the pattern as possible are guessed.

Now, let us give some consideration to "the school projected along long-line". For beneficial to the methodological meaning, I wish to define here what-we-call school the individuals forming the short intervals arranged successively, although I treated hitherto it involuntary like this. Accordingly, if the length, $k$, which is the maximum length capable of being regarded as the short interval, is determined, the number of the intervals each as long as or shorter than $k$, when all individuals are distributed by chance, is estimative from the theoretical-values in the interval analysis. But it is naturally able to be expected that there will be some short intervals arranged successively, even if all individuals are distributed by chance; and the expectant number of the lots constituted of $W$ successive intervals each of which is as long as or shorter than $k$, when all individuals are scattered by chance, is computable

adopting the method mentioned in the below.

Let us set that $N$ individuals are hooked by a row. Then, total number of the intervals nipped by the individuals is $(N-1)$; while the number of the intervals as long as or shorter than $k$ hook-interval width is $\sum_{k=1}^{k} \mathcal{V}_{(k)}$, which is estimative from the formulae in the interval analysis. Therefore, the probability of any interval as long as or shorter than $k$ hook-interval width is $P_{i(k)}=\frac{\sum_{k=1}^{k} \mathcal{V}_{(k)}}{N-1}$. And the number of the manner picking up the lot of $W$ successive intervals from $(N-1)$ intervals arranged along a line is $\{(N-1)-(W-1)\}$. Among them, to begin counting $W$ successive intervals from the foremost interval or to end in the hindmost interval lack each one of the preceding or succeeding interval, but other $W$ successive intervals of $\{(N-1)-(W-1)-2\}$ manner are nipped by other intervals. Accordingly, the expectant number in the occurrence of $W$ successive intervals, each of which is as long as or shorter than $k$ hook-intervals and located between the intervals longer than $k$ hook-interval width, is

$$(N-W-2)\,[P_{i(k)}]^W[q_{i(k)}]^2$$

while that of the terminal $W$ successive intervals sectioned by longer interval is

$$2[P_{i(k)}]^W[q_{i(k)}]$$

And the sum is

$$S_{(Wk)}=[P_{i(k)}]^W[q_{i(k)}][(N-W-2)q_{i(k)}+2] \quad \cdots\cdots(29)$$

while when $W=N-1$,

$$S_{(Wk)}=[P_{i(k)}]^W$$

Then, the number of the schools constituted of $(W+1)$ individuals caused as the results of the schooling tendency is estimated to be as equal as the difference in the observed-value from the corresponding estimated one.

Accordingly, the most important key point is how to determine the key-length, $k$. And when the observed-values of the interval analysis in the range from 0 to $k_1$ exceed continuously the estimated-values, this $k_1$ seems to be, of course, one of the most valid key-lengths (for the school in which the individuals are hooked self-spacingly, the maximum length of the first peak of the observed-values may be substituted in place of this length); while it can not be the exclusive key-length, but may be the key-length of considering the most basic structure, and the structures of higher orders may be able to be discussed substituting respective $k$, where the observed-values in the interval analysis exceed the estimated ones, into this $k_1$.

But before discussing the actually analyzed examples, I must call some attention to the fact that this method can be effectively adopted only in the example in which considerably many individuals are hooked, because of the following reasons: the total number of the intervals is limited to be $(N-1)$ and each apparent school is constituted chiefly of group of the intervals and partly of single ones, consequently, the total number of even the apparent schools has to be far less than $(N-1)$ and the number of the apparent schools of respective population sizes must be, naturally,

far less, moreover the number of the actual schools of respective population sizes due to the schooling tendency is extremely scarce, because the number of the actual schools due to the schooling tendency is as equal as the difference in the observed number from the estimated one. Accordingly, the actual analyses are tried only on the distribution patterns of the yellow-fin tuna, because I am afraid that the poor total-catch has much risk to introduce severe influence of accidental error, although the fact we know earnestly is rather the difference in the pattern with species. Moreover, during the decoding, the following fact should be kept in mind that the influence of the presence of the buoy-lines is not yet excluded from the theoretical-values. Accordingly, despite of the fact that the formula shows as if to be observable the lots constituted of more than three intervals of each one hook-interval wide arranged successively, although they are not so many, none of such a lot can occur actually, because the buoy-lines interrupt the occurrence in such a case. But so far as I have been concerned, —— within such a number of main-lines (from 350 to 400 baskets) and within such a low occupied-rate (lower than 20 %) as in the actual examples——, these imaginal theoretical-values can not reach such a high value as incapable of being regard as equal as zero. And also a half number of the lots of two or three intervals of each two hook-intervals long arranged successively is, in fact, the imaginal one occurrence of which is interrupted by the buoy-lines, and the ratio of such imaginal ones decreases with increase in $k$ and with decrease in $W$. Accordingly, the presence of the buoy-lines makes the theoretical-values computed from this formula involuntary to show a slightly contagious distribution. But there seems to be no need to exclude the influence of the presence of the buoy-lines committing against many difficulties, because the observed-values are usually biased from the estimated ones with this error to the counter direction to the expectant theoretical-values free from this error, or, even if the same direction, large difference incapable of neglecting can not be found between the observed-values and the estimated ones with this error; these mean that the distribution pattern actually observable in the examples is more contagious than or as contagious as the estimated-values with this error. Therefore, the estimated-values, in which the influence of the presence of the buoy-lines is not excluded, are computed and the distribution patterns of the yellow-fin tuna in respective examples are examined.

## Results

### 1. Exposition of particular example

**Example Y 1**

*Structure at the elemental step* ($k = 2$): The groups of the individuals forming the lots constituted of single or successively arranged intervals of as long as or shorter than two hook-intervals are regarded to be the apparent elemental-clusters,

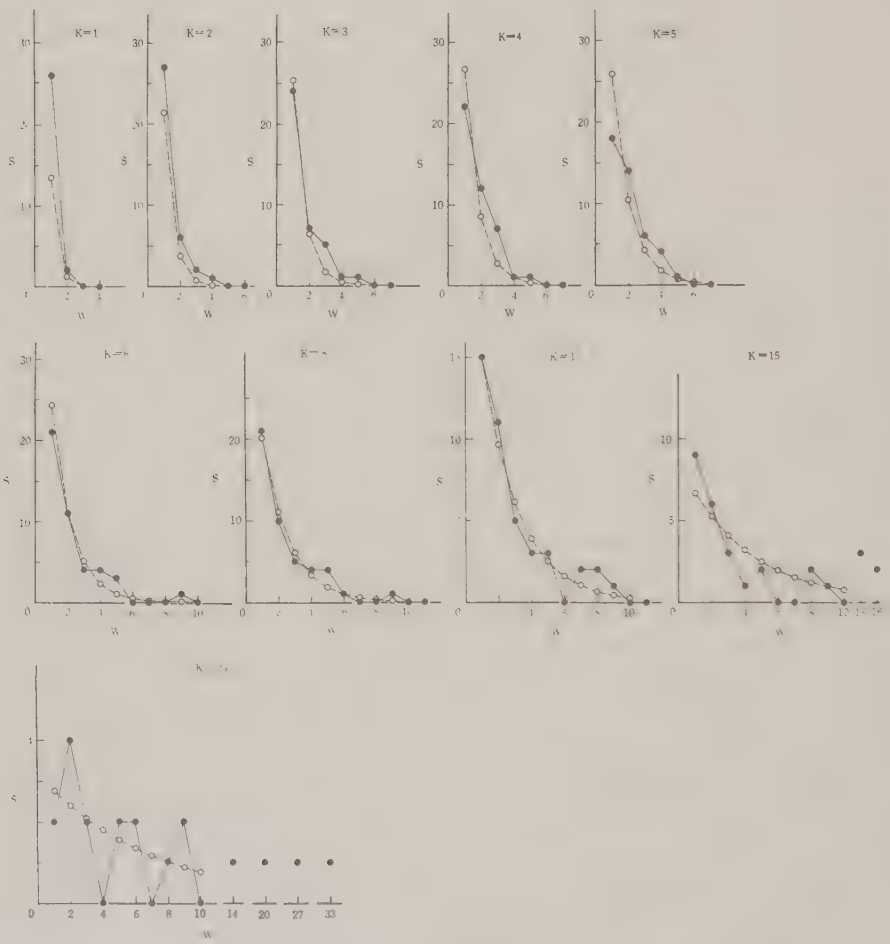


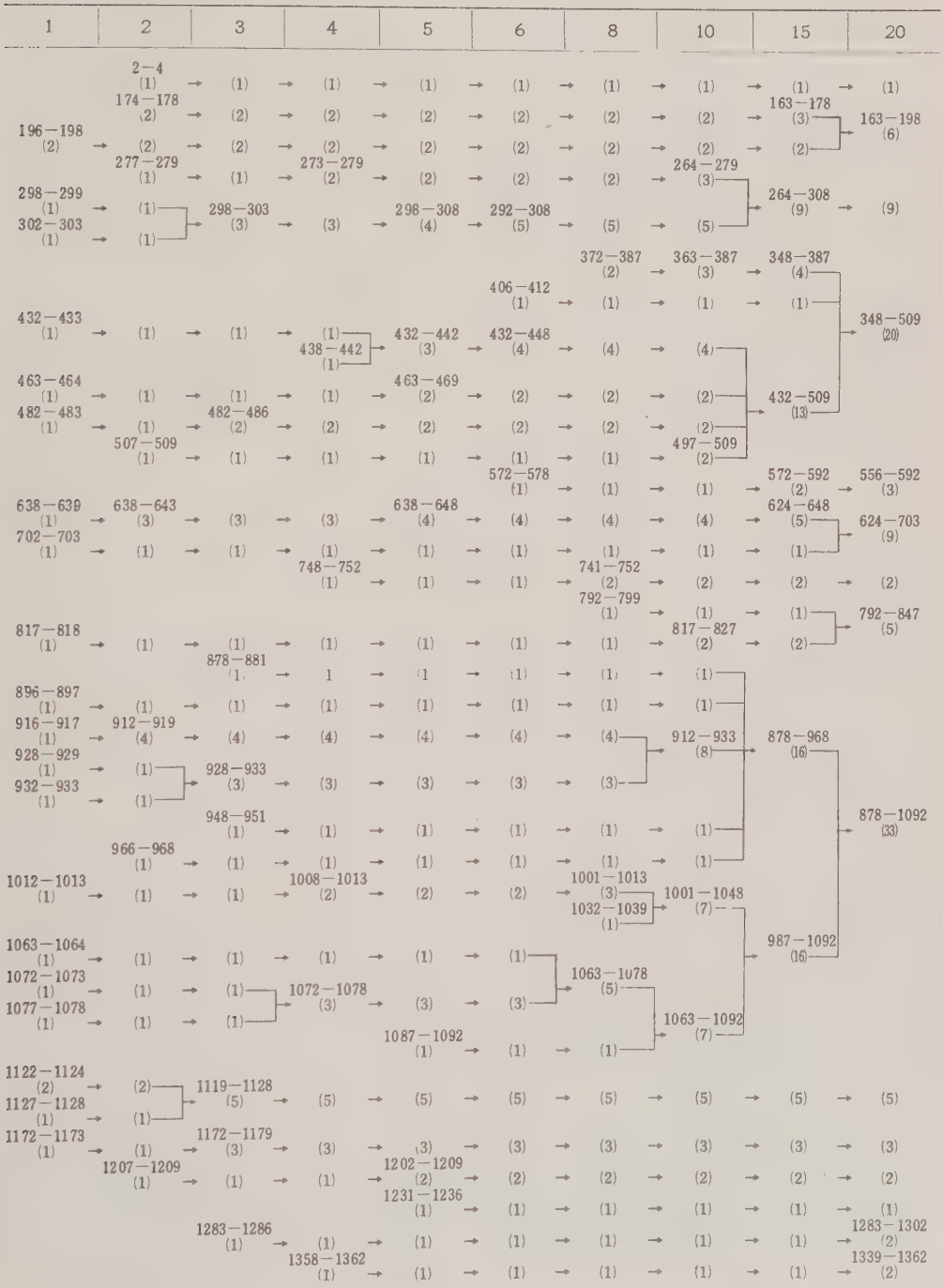

Fig. 50. The deviation of the numbers of the apparent clusters of respective population sizes, in contrast with that of the theoretically estimated numbers of the false clusters, when respective $k$ are set to be the key-lengths to decoding the distribution patterns (Example Y 1 ).

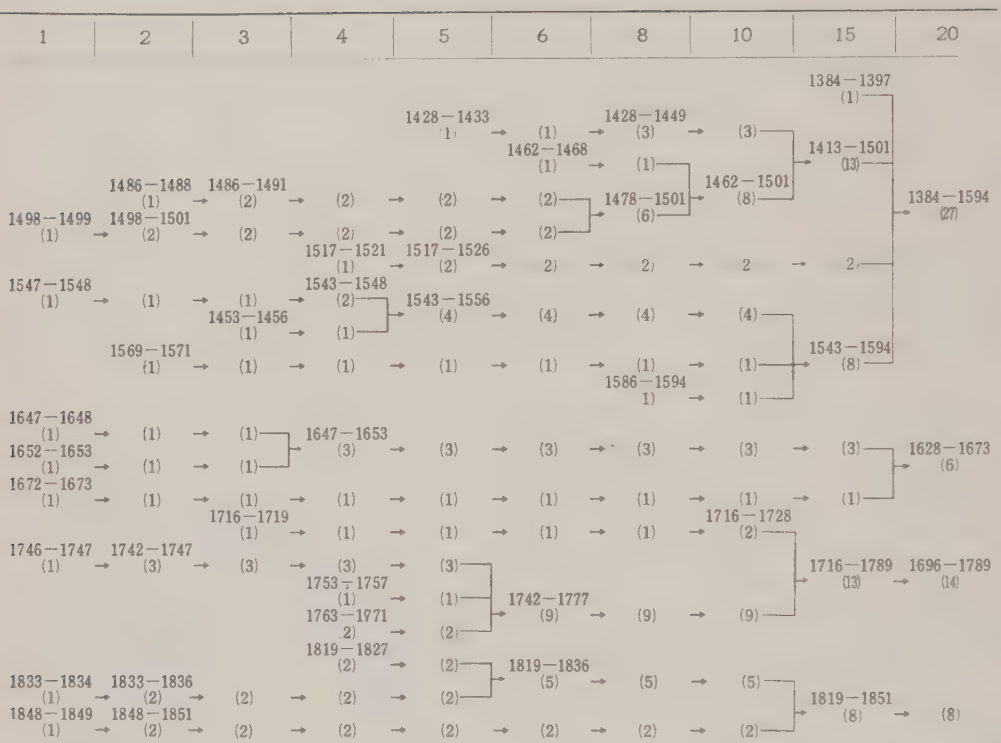
Notes (common to Figs. 50~61) :

The solid circles show the numbers of the apparent clusters, while the open ones do the theoretical numbers of the false ones. "$k$" is the key-length in hook-interval. $(W+1)$ is the population size of clusters.

because the strong contagiousness extending to two hook-intervals is suggested from the interval analysis. But even if all individuals are distributed by chance, there are some lots constituted of single or successively arranged intervals of such a length, and the expectant number in the occurrence of the lots of $W$ successive intervals (including single ones) constituted of the intervals as long as or shorter than $k$, when all individuals are distributed by chance, is computed from Formula (29). Ac-

Table 11. The positions of the apparent clusters and the changes in their features with increase in $k$ (Example Y 1).






Note for Tables 11∼22:

1) Number not enclosed in brackets indicates "Hook Number". While that of enclosed indicates the number of intervals constituting the lot. Accordingly, the value which is as large as this number plus 1 becomes number of individuals forming the lot.

2) All hooks and buoy-lines, excepting the buoy-lines of terminals of a row, are numbered from beginning to hauling. And this number is called as Hook Number. Consequently, the *Ath* hook in the *Bth* basket is named as a hook of "Hook Number 5(B−1)+A".

cordingly, among the apparent-clusters of respective population-sizes, the numbers of which are represented as the observed-values in Fig. 50 — (2), those caused by the schooling tendency are illustrated as the difference in the observed-values from the estimated ones. When discussed the schooling tendency, the individuals, falsely forming the lots constituted of single or successively arranged intervals expected to be caused even if all the individuals are distributed by chance, should be also regarded as the single individuals, although they seem, in appearance, as if to form clusters. Therefore, the structure at the elemental step is guessed as follows: the population is constituted of 11 true-clusters, which are six pairs of individuals, two clusters constituted of each three individuals, two clusters of each four individuals and a cluster of five individuals, mingling with about 150 single individuals. And the hooked positions of the elemental-clusters constituted of four or one more hooked-individuals are easily estimative from Table 11; while for the rests of them, it is very hard to estimate the hooked positions, because we can hardly distinguish the

true elemental-clusters due to the schooling tendency from the false ones caused by the chance distribution.

*Structure at the second order* ($k = 15$): Then the feature of the cluster-formation at the next order can be deduced from Fig. 50—(15), in which $k$ is elongated into as long as 15 hook-intervals, because the second peak of the observed-values in the interval analysis is found around $k=15$. But, for the attempt not only to use as one of the auxial proofs to distinguish the clusters due to the schooling tendency from those caused by the chance distribution but also to represent the feature of the appearance, disappearance and fusion of the clusters at respective steps of increase in $k$, the results of the analyses in which $k$ is increased step by step are also represented in Table 11 and Figs. 50—(3), (4), (5), (6), (8), and (10). The observed numbers of the apparent-clusters constituted of as equal as or less than 10 hooked-individuals are not so far from the corresponding theoretical ones, as represented in Fig. 50; therefore, there is no need to consider that any of them is the true-cluster caused by the schooling tendency. But among three apparent-clusters constituted of each 14 hooked-individuals and two apparent ones of each 17 hooked-individuals, at least three or one more clusters are thought to be due to the schooling tendency and are regarded as the true-clusters. And the results at lower steps of the analyses considered together, they are thought to be hooked in the ranges, respectively from the third hook in the 176th basket (Hook Number 878) to the hook of the same order spaced by 18 baskets (H. N. 968) (constituted of 17 hooked-individuals), from the second hook in the 198th basket (H. N. 987) to the hook of the same order spaced by 21 baskets (H. N. 1092) (also 17 individuals), from the third hook in the 283th basket (H. N. 1413) to the first hook in the 301th basket (H. N. 1501) (14 hooked-individuals) and from the first hook in the 344th basket (H. N. 1716) to the last hook in the 358th basket (H. N. 1789) (also 14 hooked-individuals), and their structures at the subordinate orders can also be assumed from this table. Here, the word "Hook Number X" which is abbreviated to *H.N.X*, is introduced; this indicates the position where the *xth* hook including the buoy-lines counting from the beginning of hauling of the gears is located, for the purpose of representing the hooked positions. Besides, another apparent aggregation of such a population-size is observable, but it can not be regarded as the true cluster, not only because one or more apparent-clusters of such a population-size have to occur even if all individuals are distributed by chance but also because no proof with it supported a true one can be found in the structure at the subordinate orders. Accordingly, the distribution pattern at this order is assumed as follows: the population is constituted chiefly of many single individuals and elemental-clusters, and mingling with them, four clusters are contained; and the individuals derived from the former group occupy $\frac{2}{3}$ of total catch, while catch from the true-clusters occupies half as many as that from the former group.

*Structure at the highest order* ($k=20$): The third peak of the observed-values in the interval analysis is found about $k=20$. Accordingly, the distribution pattern deducible

from Fig. 50 — (20), in which a width of 20 hook-intervals is adopted as the key-length, may be that of the highest order observable within a row, because the intervals longer than 20 hook-intervals are only as many as $\frac{1}{10}$ of total ones moreover the observed-values and the estimated ones in the interval analysis in the range $k>20$ are extremely scarce, which makes it impossible to give any significance to the difference in the observed-values from the estimated ones. Here, if the individuals are distributed showing gradient, the hooked positions of the true-schools should be determined by considering the influence of the gradient of the distribution together with the structure at the subordinate orders, because the gradient influences the apparent-schools as if the more frequently hooked at the latter parts of the hauling in a row. But there is no need to pay any attention to the influence of the gradient, because not so strong gradient is alluded to. If neglecting the small deviations, Fig. 50 — (20) shows that the observed numbers of the clusters each constituted of from two to 11 hooked-individuals are not so far from the corresponding estimated ones which represent the numbers caused by the chance distribution; accordingly, none of the apparent-schools of such population-sizes are regarded as the true one caused by the schooling tendency. And concerning an apparent-cluster constituted of 15 hooked-individuals, no fact suggesting us whether it can be regarded as the true one or the false one is found out from this figure, but the structure at the subordinate order suggests us that it is more reasonable to regard this as the true-cluster caused by the schooling tendency. It may safely be considered that three apparent-schools constituted of 21, 28 and 34 hooked-individuals respectively are due to the schooling tendency; and they are thought to cover the ranges from the third hook in the 70th basket (H.N. 348) to the last hook in the 102th basket (H.N. 509) (constituted of 21 hooked-individuals), from the third hook in the 176th basket (H.N. 878) to the second hook in the 219th basket (H.N. 1092) (34 hooked-individuals) and from the last hook in the 277th basket (H.N. 1384) to the hook of the same order spaced by 42 baskets (H.N. 1594) (28 hooked-individuals), and the probable one constituted of 15 hooked-individuals is assumed to be hooked in the range from the first hook in the 340th basket (H.N. 1696) to the last hook in the 358th basket (H.N. 1789). And their structures at the subordinate order can also be easily deduced from this table. Thus, about 46 % of total catch are occupied by the individuals forming four true-schools, while the rests of it are by the individuals swimming solitarily or forming the aggregations at respective steps of the subordinate orders.

But lastly, I have to describe clearly the fact that even the average occupied-rates of the hooks in the parts, where these true schools are hooked, are not so high as impressed superficially from the word "school", but are from 0.16 to 0.20, which are from 35 % to 65 % higher than that computed from throughout a row. Accordingly, the distribution pattern is thought to be not so different from the chance distribution as superficially impressed, because the chance distribution does not mean that the occupied-rate is throughout the same, but some dense and diverse are naturally expectable.

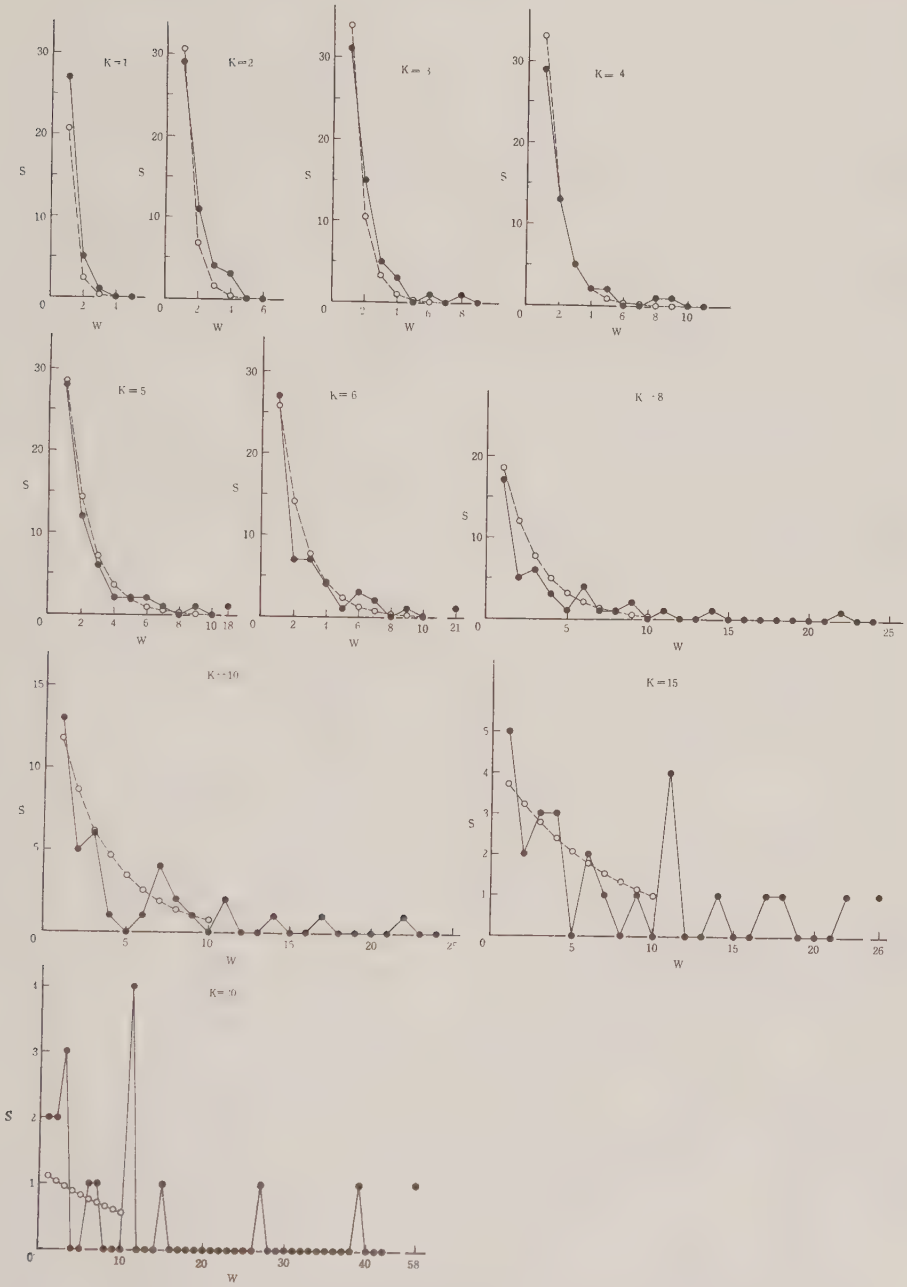
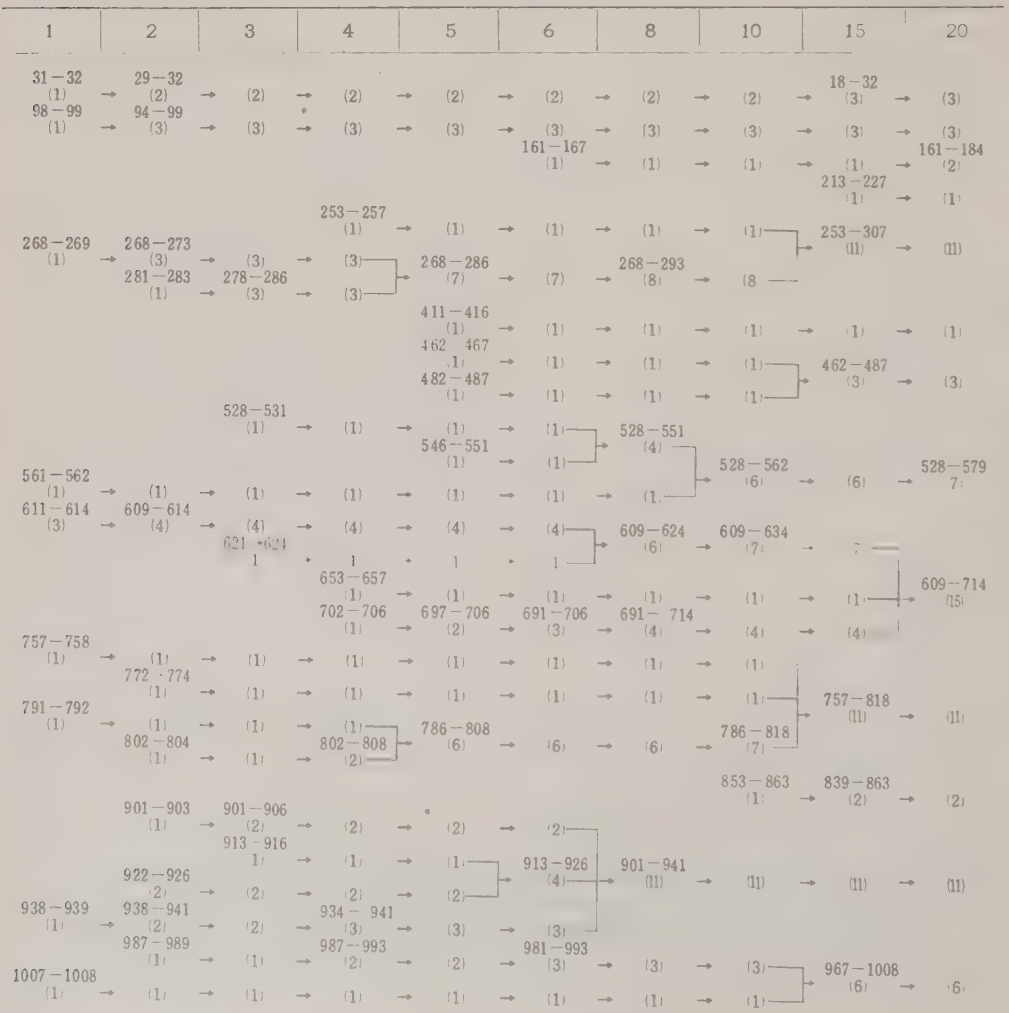


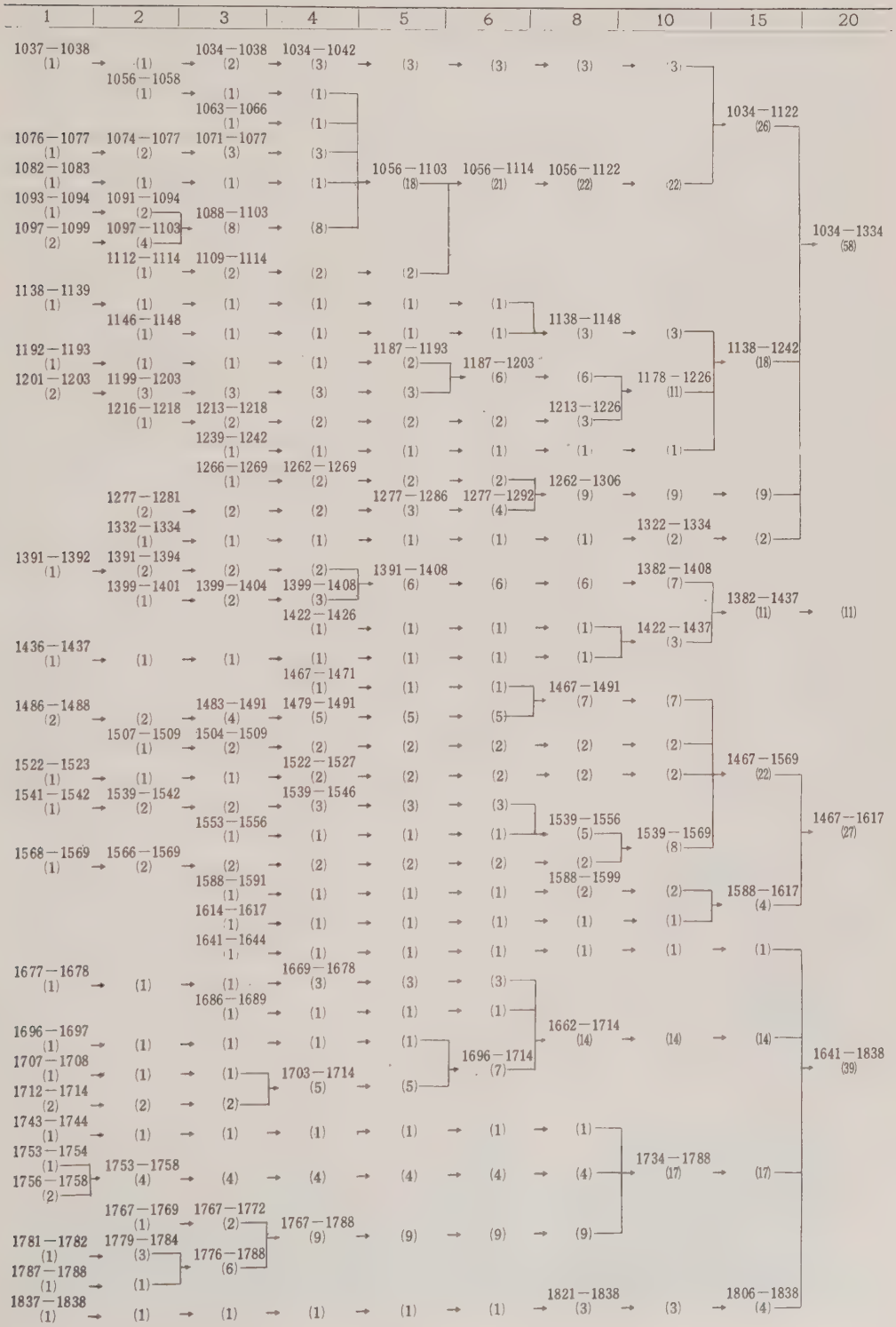

Fig. 51. The deviation of the numbers of the apparent clusters of respective population sizes, in contrast with that of the theoretically estimated numbers of the false clusters, when respective $k$ are set to be the key-lengths to decoding the distribution patterns (Example Y 2 ).

## Example Y 2

*Structure at the elemental step* ($k = 3$) : The observed-values in the range from $k = 1$ to 3 hook-intervals in the interval analysis are continuously higher than the estimated ones; this means that the lots of single or successively arranged intervals constituted of the intervals each covering as long as or shorter than three hook-intervals, are regarded as the apparent elemental-clusters. But Fig. 51—(3), in which the result of the arrangement analysis (key-length : $k = 3$) is represented, tells us that only eight clusters —— which are four clusters constituted of each three hooked-individuals among 15 apparent ones, two clusters each constituted of four hooked-individuals among five and two of the five hooked-individual clusters among

Table 12 a. The positions of the apparent clusters and the changes in their features with increase in $k$ (Example Y 2).




1 2 3 4 5 6 8 10 15 20
1037−1038 (1) → (1)
1034−1038 (2) → 1034−1042 (3) → (3) → (3) → (3) → 3
1056−1058 (1) → (1) → (1)
1063−1066 (1) → (1)
1076−1077 (1) → 1074−1077 (2) → 1071−1077 (3) → (3)
1082−1083 (1) → (1) → (1) → (1)
1056−1103 (18) → 1056−1114 (21) → 1056−1122 (22) → (22)
1034−1122 (26)
1093−1094 (1) → 1091−1094 (2)
1097−1099 (2) → 1097−1103 (4)
1088−1103 (8) → (8)
1034−1334 (58)
1112−1114 (1) → 1109−1114 (2) → (2) → (2)
1138−1139 (1) → (1) → (1) → (1) → (1) → (1)
1146−1148 (1) → (1) → (1) → (1)
1138−1148 (3) → (3)
1192−1193 (1) → (1) → (1) → (1)
1187−1193 (2) → 1187−1203 (6) → (6)
1138−1242 (18)
1201−1203 (2) → 1199−1203 (3) → (3) → (3)
1178−1226 (11)
1216−1218 (1) → 1213−1218 (2) → (2) → (2) → (2)
1213−1226 (3)
1239−1242 (1) → (1) → (1) → (1) → (1) → (1)
1266−1269 (1) → 1262−1269 (2) → (2)
1262−1306 (9) → (9) → (9)
1277−1281 (2) → (2) → (2) → 1277−1286 (3) → 1277−1292 (4)
1332−1334 (1) → (1) → (1) → (1) → (1) → (1)
1322−1334 (2) → (2)
1391−1392 (1) → 1391−1394 (2) → (2) → (2)
1391−1408 (6) → (6) → (6)
1382−1408 (7)
1399−1401 (1) → 1399−1404 (2) → 1399−1408 (3)
1382−1437 (11) → (11)
1422−1426 (1) → (1) → (1) → (1)
1422−1437 (3)
1436−1437 (1) → (1) → (1) → (1) → (1) → (1)
1467−1471 (1) → (1)
1467−1491 (7) → (7)
1486−1488 (2) → 1483−1491 (4) → 1479−1491 (5) → (5) → (5)
1507−1509 (1) → 1504−1509 (2) → (2) → (2) → (2) → (2) → (2)
1522−1523 (1) → (1) → (1) → 1522−1527 (2) → (2) → (2) → (2) → (2)
1467−1569 (22)
1541−1542 (1) → 1539−1542 (2) → 1539−1546 (3) → (3)
1553−1556 (1) → (1) → (1) → (1)
1539−1556 (5)
1539−1569 (8)
1467−1617 (27)
1568−1569 (1) → 1566−1569 (2) → (2) → (2) → (2) → (2) → (2)
1588−1591 (1) → (1) → (1) → (1)
1588−1599 (2) → (2)
1588−1617 (4)
1614−1617 (1) → (1) → (1) → (1) → (1) → (1)
1641−1644 (1) → (1) → (1) → (1) → (1) → (1) → (1)
1677−1678 (1) → (1) → (1)
1669−1678 (3) → (3)
1686−1689 (1) → (1) → (1) → (1)
1696−1697 (1) → (1) → (1) → (1) → (1)
1662−1714 (14) → (14) → (14)
1707−1708 (1) → (1) → (1)
1703−1714 (5) → (5)
1696−1714 (7)
1641−1838 (39)
1712−1714 (2) → (2) → (2)
1743−1744 (1) → (1) → (1) → (1) → (1) → (1) → (1)
1753−1754 (1)
1753−1758 (4) → (4) → (4) → (4) → (4) → (4)
1734−1788 (17) → (17)
1756−1758 (2)
1767−1769 (1) → 1767−1772 (2)
1767−1788 (9) → (9) → (9) → (9)
1781−1782 (1) → 1779−1784 (3)
1776−1788 (6)
1787−1788 (1) → (1)
1837−1838 (1) → (1) → (1) → (1) → (1) → (1)
1821−1838 (3) → (3)
1806−1838 (4)

three —— are regarded as the true-clusters at the elemental step; and although the hooked positions of the apparent-clusters of such population-sizes are represented in Table 12 a, those of the true ones are not certain because it is very hard to distinguish the true ones from the false ones. But concerning two apparent-clusters constituted of each more than six hooked-individuals, there may be no doubt that they are caused by the schooling tendency, consequently they are regarded as the true ones. And they are guessed to cover the ranges respectively from the third hook in the 218th basket (H.N. 1088) to the third hook in the 221th basket (H.N. 1103) (constituted of nine hooked-individuals) and from the first hook in the 356th basket (H.N. 1776) to the third hook in the 358th basket (H.N. 1788) (seven hooked-individuals). Therefore, 46 hooked-individuals, which occupy 20 % of total catch, are thought to form 10 elemental-clusters, while the rests of it are swimming as single individuals.

*Structure at the highest order* ($k = 15$) : The second peak of the observed-values in the interval analysis is found at $k = 14$. And the structure at this step may be that of the highest order observable within a row, because there is no conspicuous third peak of the observed-values, although some fusion and appearance of the apparent- and the true-clusters may occur with increase in $k$ into the range longer than 15 hook-intervals. But these two key-lengths ($k = 3$ and 15 hook-intervals) are too apart from each other, moreover there are two peak-like high observed-values between them; accordingly, it seems to be of interest and of necessity to examine on the feature of appearance, disappearance and fusion of the apparent-clusters and the true ones with increase in key-length, in order not only to find out the distribution pattern but also to examine whether it is acceptable to guess the key-lengths from the figures representing the results of the interval analysis or not. Accordingly, let us examine carefully on Table 12 a and Figs. 51 — (3), (4), (5), (6), (8), (10), and (15). Then we will obtain Table 12 b, in which the changes in the features of the apparent-

Table 12 b. Changes in the number of the apparent clusters and that of the true ones with increase in key-length from 3 to 15 hook-intervals (Example Y 2).

| Key length | 3 | 4 | 5 | 6 | 8 | 10 | 15 |
|---|---|---|---|---|---|---|---|
| Apparent clusters | | | | | | | |
| Total number | 56 | 53 | 55 | 53 | 43 | 38 | 26 |
| Appearance | — | 5 | 4 | 1 | 0 | 1 | 0 |
| Fusion | — | 12 | 7 | 7 | 14 | 9 | 12 |
| True clusters | | | | | | | |
| Number | 10 | 3 | 4 | 4 | 5 | 4 | 6 |

Notes:

1 ) Numerals in column "appearance" indicate the number of newly-appeared clusters. Accordingly, all the intervals constituting such a cluster are longer than $k$ of the preceding step while as long as or shorter than $k$ of respective steps.

2 ) Numerals in column "fusion" indicate the number of clusters, the population size of which is increased by fusion with single individuals or with any other apparent clusters.

clusters and the true ones with increase in key-length are summarized; and this table tells us the following facts: 1) total number of the apparent-clusters decreases rather constantly 2.5 clusters per increase in $k$, 2) as few as negligible number of the apparent-clusters appears newly when $k$ is increased to the width longer than five hook-intervals, 3) the number of the apparent-clusters, the population-size of which swells by fusion with single individuals or with other clusters, decreases slightly with increase in key-length, while it keeps considerable number and their rate on total number of the apparent-clusters is almost invariable or rather slightly increased, 4) number of the true-clusters is invariable regardless of increase in key-length to the range longer than four hook-intervals, although some of them become impossible to be regarded as the true ones, because the theoretical numbers of the clusters of large population-sizes increase with key-length, while some other apparent-clusters swell their population-sizes into the values capable of being regarded as the true ones and 5) thus, the population-size of the true-clusters tends to increase with key-length.

And at last when the key-length is elongated into as long as 15 hook-intervals, the population gets to show such a distribution pattern as mentioned below: a half of the catch is constituted of single individuals which are swimming solitarily or forming the false-clusters; and mingling with them, there are six true-clusters which occupy the other half of catch. And the larger five of them are thought to be hooked in the ranges respectively from the second hook in the 333th basket (H.N. 1662) to the last hook in the 343th basket (H.N. 1714) (constituted of 15 hooked-individuals), from the last hook in the 347th basket (H.N. 1734) to the third hook in the 358th basket (H. N. 1788) (18 hooked-individuals), from the third hook in the 228th basket (H.N. 1138) to the second hook in the 249th basket (H.N. 1242) (19 hooked-individuals), from the last hook in the 207th basket (H.N. 1034) to the second hook in the 225th basket (H.N. 1122) (27 hooked-individuals) and from the second hook in the 294th basket (H.N. 1467) to the last hook in the 314th basket (H.N. 1569) (23 hooked-individuals); while the other cluster constituted of 12 hooked-individuals is thought to cover one of the following four ranges where the apparent-clusters of such a population-size are hooked —— from the third hook in the 51th basket (H. N. 253) to the second hook in the 62th basket (H.N. 307), from the second hook in the 152th basket (H.N. 757) to the third hook in the 164th basket (H.N. 818), from the first hook in the 181th basket (H.N. 901) to the hook of the same order spaced by 8 baskets (H.N. 941) or from the second hook in the 277th basket (H.N. 1382) to the hook of the same order spaced by 11 baskets (H.N. 1437) —— but the third range is the most probable.

Here, I wish to call attention to the fact that the average occupied-rates of the hooks in the parts covered by these true-clusters are at most three times as high as that computed from throughout a row while the lowest one is only $1\frac{1}{2}$ times as high as that computed from throughout a row, because I am afraid that the word "true-cluster" has much risk to impress too strongly as if to indicate the part of considerably high occupied-rate; thus the distribution pattern of this example, when

to consider throughout a row as a whole, is also not so different from the chance distribution as impressed superficially, because even if all the individuals are distributed by chance a little weak deviation of partial occupied-rates is, of course, expected.

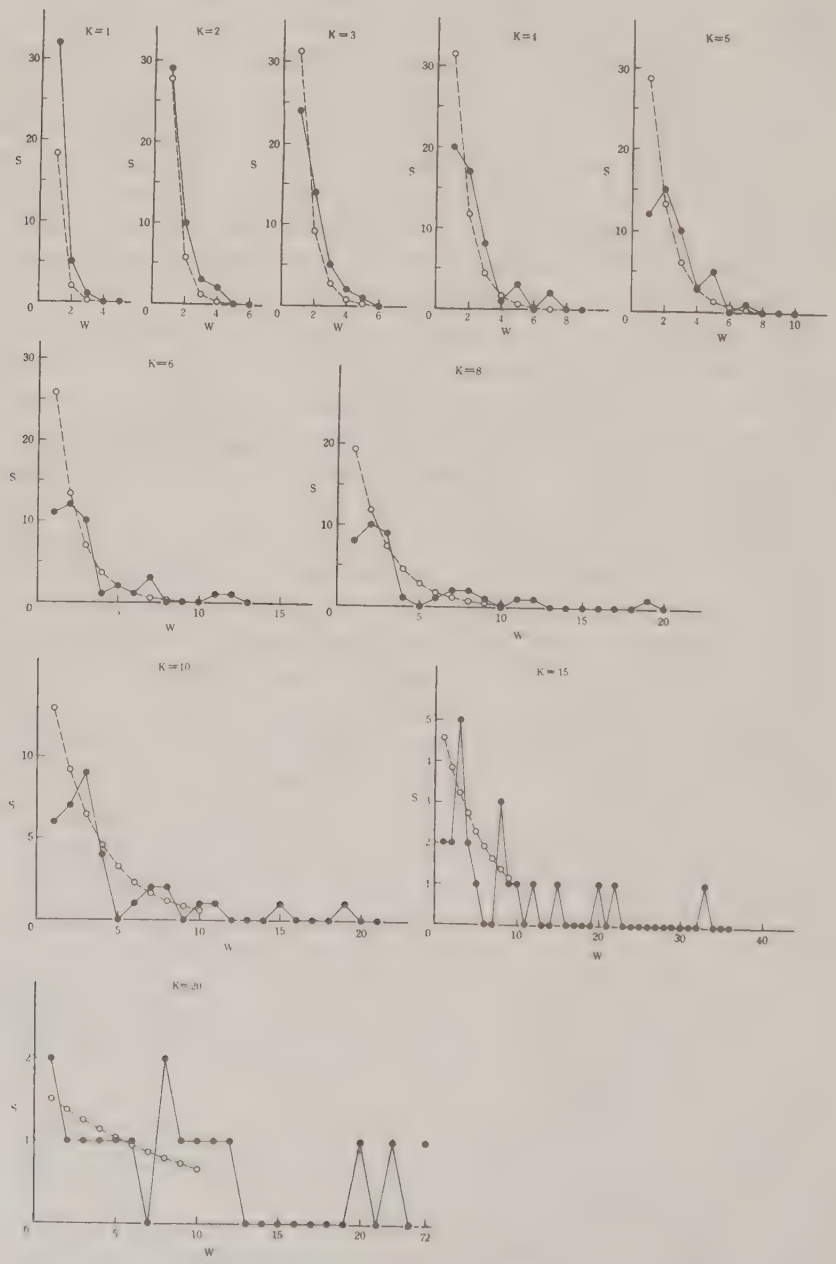


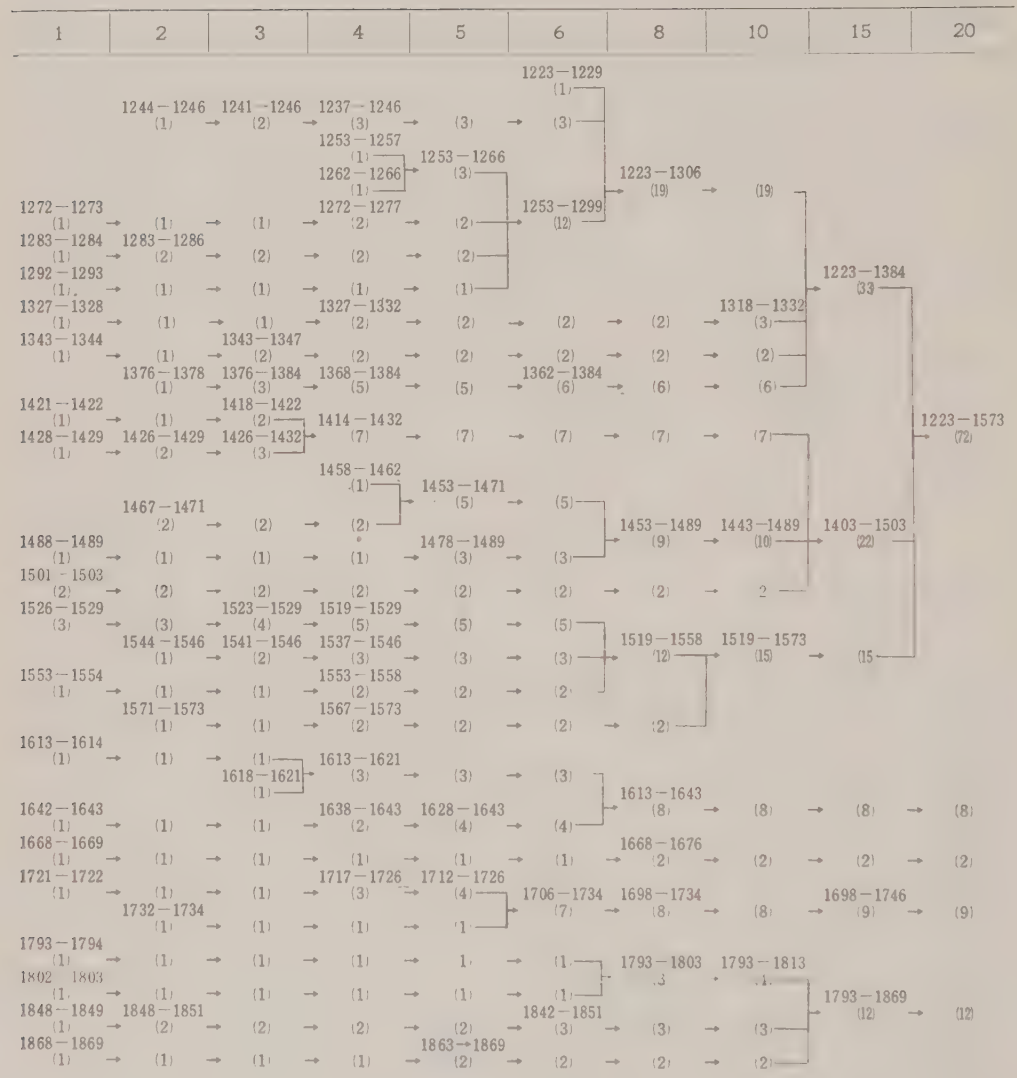

Fig. 52. The deviation of the numbers of the apparent clusters of respective population sizes, in contrast with that of the theoretically estimated numbers of the false clusters, when respective $k$ are set to be the key-lengths to decoding the distribution patterns (Example Y 3 ).

## Example Y 3

*Structure at the elemental step* ($k = 1$) : The observed-value in the interval analysis at $k = 1$ is far higher than the estimated one, while that at $k = 2$ is nearly as equal as the estimated one. Accordingly, the apparent elemental-clusters are thought to be constituted of the individuals hooked successively. And 18 clusters, —— which are 14 pairs of the individuals hooked successively among 32 apparent ones, three clusters constituted of each three successively hooked individuals among five apparent ones and a basket fully occupied, —— are thought to be the true-clusters at the elemental step caused by the schooling tendency. And the hooked positions of these true ones, except the largest one, are uncertain because of the difficulty in distinguishing of

Table 13. The positions of the apparent clusters and the changes in their features with increase in $k$ (Example Y 3).

| 1 | 2 | 3 | 4 | 5 | 6 | 8 | 10 | 15 | 20 |
|---|---|---|---|---|---|---|---|---|---|
| 27—29 (2) | → (2) | → 27—32 (3) | → (3) | → (3) | → (3) | → (3) | → (3) | → (3) | → (3) |
| | | | | | | | | | 88—107 (1) |
| | | | 249—257 (2) | → 249—262 (3) | → (3) | → (3) | → (3) | → (3) | → 213—262 (5) |
| | | | | | | | 403—413 (1) | → 379—413 (3) | |
| 431—432 (1) | → 429—432 (2) | → (2) | → (2) | → (2) | → (2) | → (2) | → (2) | → (2) | → 379—432 (6) |
| | | | | | | | | 474—489 (1) | → (1) |
| | 549—551 (1) | → 546—551 (2) | → (2) | → (2) | → (2) | → 546—558 (3) | → 537—558 (4) | → (4) | |
| 577—578 (1) | → (1) | → (1) | → (1) | → (1) | → (1) | → (1) | → 577—588 (2) | → 577—603 (3) | → 573—629 (10) |
| | | | | | 623—629 (1) | → (1) | → (1) | → (1) | |
| 693—694 (1) | → (1) | → (1) | → (1) | → (1) | → (1) | → 693—704 (4) | → (4) | → (4) | → (4) |
| 702—704 (2) | → (2) | → (2) | → (2) | → (2) | → (2) | | | | |
| 726—727 (1) | → (1) | → (1) | → (1) | → (1) | → (1) | → 726—742 (3) | → (3) | → 726—783 (8) | |
| 772—773 (1) | → (1) | → (1) | → (1) | → 767—773 (2) | → (2) | → (2) | → 767—783 (3) | | |
| 803—804 (1) | → 801—804 (2) | → (2) | → (2) | → (2) | → (2) | → (2) | → (2) | → 801—818 (3) | → 726—894 (22) |
| 856—858 (2) | → 854—858 (3) | → (3) | → (3) | → (3) | → (3) | → (3) | → (3) | → 854—894 (8) | |
| 877—878 (1) | → (1) | → 877—881 (2) | → 873—881 (3) | → (3) | → (3) | → (3) | → (3) | | |
| 927—929 (2) | | | | | | | | | |
| 931—932 (1) | → 927—932 (4) | → 924—932 (5) | → (5) | → (5) | | | | | |
| | | | | | 924—949 (11) | → (11) | → (11) | | |
| 943—944 (1) | | | | | | | | | |
| 948—949 (1) | → 943—949 (4) | → (4) | → (4) | → 938—949 (5) | | | | | |
| | | | 977—981 (1) | → (1) | → (1) | → (1) | → (1) | → 924—1023 (20) | → (20) |
| | | 994—997 (1) | → (1) | → (1) | → (1) | → (1) | → 994—1011 (4) | | |
| 1006—1007 (1) | → (1) | → (1) | → 1006—1011 (2) | → (2) | → (2) | → (2) | | | |
| 1046—1047 (1) | → (1) | → (1) | → (1) | → (1) | → (1) | → (1) | → (1) | | |
| 1073—1074 (1) | → (1) | → (1) | → (1) | → 1073—1088 (4) | | | | → 1046—1098 (10) | → 1046—1116 (11) |
| | | | 1084—1088 (1) | → | → 1073—1098 (7) | → (7) | → (7) | | |
| | 1094—1098 (2) | → (2) | → (2) | → (2) | | | | | |
| 1137—1138 (1) | → (1) | → (1) | → (1) | → (1) | → (1) | → (1) | → (1) | → 1137—1156 (5) | → 1137—1196 (8) |
| 1153—1154 (1) | → 1151—1156 (3) | → (3) | → (3) | → (3) | → (3) | → 1176—1183 (1) | → (3) | | |
| | | | | | | | → (1) | → 1176—1196 (2) | |




the true-clusters from the false ones, although the hooked positions of all the apparent elemental-clusters are illustrated in Table 13. Accordingly single individuals, which are swimming solitarily or forming the false-clusters caused even as the results of the chance distribution, occupy 4/5 of çatch, while the rests of it form 18 elemental-clusters.

*Structure at the second order* ($k=4$) : The features of the cluster-formation at the second order can be guessed out from Fig. 52 — (4) and Table 13, in which $k$ is elongated into four hook-intervals, because the second peak of the observed-values in the interval analysis is found at $k = 4$. And let us consider the distribution pattern of this order, referring to the structure at the subordinate steps together.

Then we will find the following facts that 1) the theoretical number of the isolated single-intervals, each of which covers the range as long as or shorter than $k$ hook-intervals, increases slightly with increase in $k$ from one to four; but contrary to this, the observed number decreases, 2) consequently when $k = 4$, the observed number is 11.4 lower than the theoretical one, although the intervals as long as or shorter than four hook-intervals are observable more frequently than expected, 3) but the clusters constituted of many successively arranged intervals are observable more frequently with increase in $k$; and this tendency exceeds the same in the theoretical-values, and 4) these facts seem to suggest that the individuals are hooked more aggregatively than they are distributed by chance. Thus, the structure at the second order is guessed as follows : none of the apparent-clusters constituted of each two hooked-individuals are regarded as the true one; moreover, 11 or one more apparent-clusters, which are expected to be observable as single intervals when all individuals are hooked by chance, are actually observable not as the single intervals but as the lots attached to some other intervals because of the schooling tendency. And among them, five clusters are attached to each one more interval, four clusters to each two more, two clusters to each three more and the other interval is attached to six intervals arranged successively; consequently these are all able to be regarded as the true-clusters. Accordingly, about a quarter of catch is thought to be derived from 12 true-clusters, while the rests of it are brought chiefly from the single individuals and partly from the single elemental-clusters of small population-size.

*Structure at the higher orders* : The clear third peak of the observed-values in the interval analysis is not found out. But the structures of the higher orders have to be discussed for reference' sake, chiefly because the presence of some obscure peak-like high observed-values in the interval analysis is suggested, moreover this key-length, four hook-interval width, seems to be too short to consider as that to the highest order observable within a row. And if such obscure peaks were regarded to be significant, the structure mentioned below in short may be guessed out.

(*Structure at the third order, $k = 15$*) : The presence of three true-clusters and a doubtful one is suggested. And the clear ones are thought to occupy the parts respectively from the last hook in the 185th basket (H.N. 924) to the third hook in the 205th basket (H.N. 1023) (constituted of 21 hooked-individuals), from the third hook in the 245th basket (H.N. 1223) to the last hook in the 277th basket (H.N. 1384) (34 hooked-individuals), and from the third hook in the 281th basket (H.N. 1403) to the hook of the same order in the 301th basket (H.N. 1503) (23 hooked-individuals); while the doubtful one is guessed to cover the range from the last hook in the 304th basket (H.N. 1519) to the third hook in the 315th basket (H.N. 1573) (constituted of 16 hooked-individuals). Thus, about 43% of catch are thought to be brought from these four true-clusters including a doubtful one, while the rests of it are from the single individuals or from the clusters of the lower orders.

(*Structure at the fourth order, $k = 20$*) : A cluster of the third order which is constituted of 21 hooked-individuals is so distinctly separated from the others that being able to be regarded as a true-school of this step, being suffered from no

change in the features. But three other clusters at the third order including a doubtful one are such faintly spaced from each other as fused into a school constituted of 73 hooked-individuals, when 20 hook-interval width is adopted as the key-length, and this is thought to cover the part from the third hook in the 245th basket (H. N. 1223) to the hook of the same order spaced by 70 baskets (H.N. 1573). Besides them, the other school constituted of 23 hooked-individuals comes to be regarded as the true-school, which is thought to be hooked in the part from the first hook in the 146th basket (H.N. 726) to the last hook in the 179th basket (H.N. 894). Accordingly, about 54% of catch are thought to be distributed within $\frac{1}{3}$ of a row forming these three schools. But we should pay attention to the fact that the average occupied-rates of the hooks in the parts covered by the former two schools are a little higher than one individual per basket while that covered by the other school is only 20% higher than the average occupied-rate computed from throughout a row. Thus, the occupied-rates are not so high, although these schools cover considerably wide ranges; accordingly, even these schools are thought to be not so strongly aggregated as superficially impressed, consequently the distribution pattern to see as a whole may be not so far from the chance distribution as superficially impressed from the above-mentioned description.

**Example Y 4**

Before entering into the discussion on the distribution pattern of this example, I must describe here the following facts, for reference' sake. Comparing the results of the interval analysis and the arrangement one of this example with those of the preceding three examples, we will be aware of the importance and the necessity of adding of the arrangement analysis, because the results of the interval analysis of this example and the preceding ones are essentially not so different, but the differences in another new characteristic of the distribution pattern of basic importance get possible to be found out, by adding the arrangement analysis. That is to say, the aggregative tendency of the preceding examples makes it possible to be observable some true-clusters constituted of a little many hooked-individuals even if $k$ is not so long, moreover observable some schools constituted of many hooked-individuals covering wide ranges when $k$ is long. Contrary to these facts, it is suggested as one of the characteristics of the distribution pattern of this example that, when $k = 6$, there is no cluster constituted of more than four hooked-individuals, and when $k = 10$, there is also no one constituted of more than 10 hooked-individuals, moreover even when $k = 20$, none of the true-clusters constituted of more than 20 hooked-individuals and covering wider range than 25 baskets are observable; thus these facts clearly suggest that only a few of clusters of extremely small population-size is regarded as the true ones, moreover they are rather somewhat evenly distributed throughout a row, consequently the population does not contain any school of large population-size and covering wide range, against the fact that more clusters including those of a little large population-size are recognized in other examples as the true ones. And

keeping these facts in mind, let us examine on the distribution patterns at respective steps.

*Structure at the elemental step* ($k = 1$ *or* 2): The observed-values in the interval analysis in the range from $k = 1$ to 4 are continuously higher than the estimated ones, but the key-length to the elemental structure is regarded to be 1 or 2 hook-intervals, because the observed-value in the interval analysis at $k=2$ is far lower than those at $k=1$ and 3, although it is still higher than the estimated one; and the key-length to the structure at the second order is thought to be 3 or 4 hook-intervals.

When we set that the key-length to the structure at the elemental step is one hook-interval, six clusters constituted of each two hooked-individuals among 16 apparent

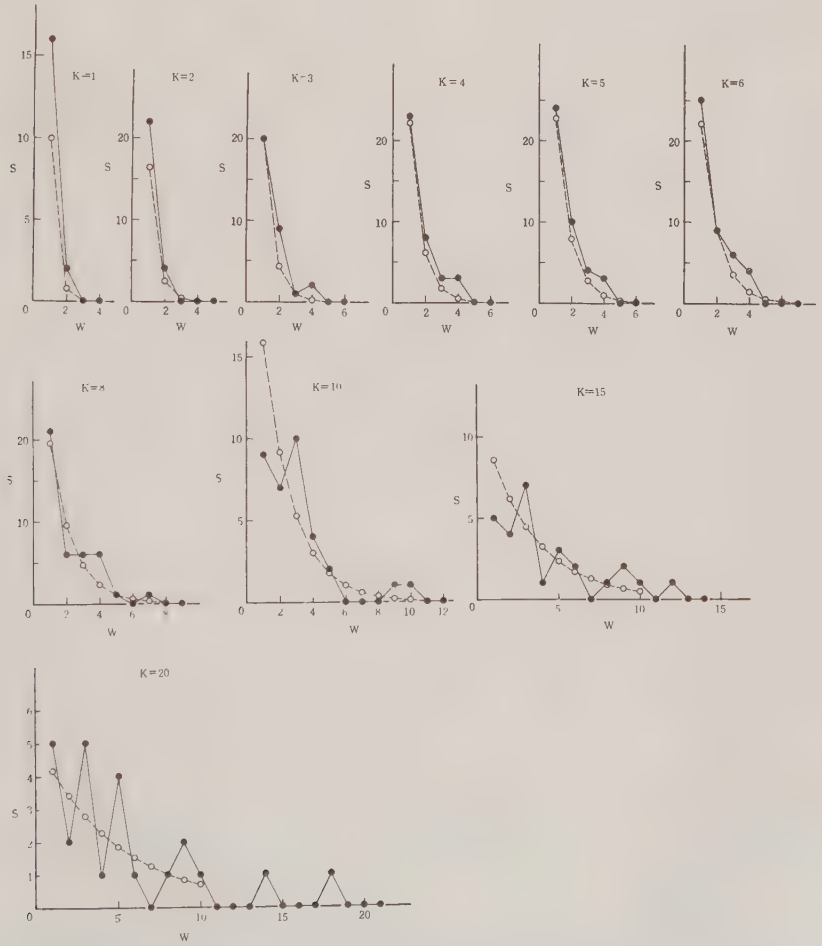
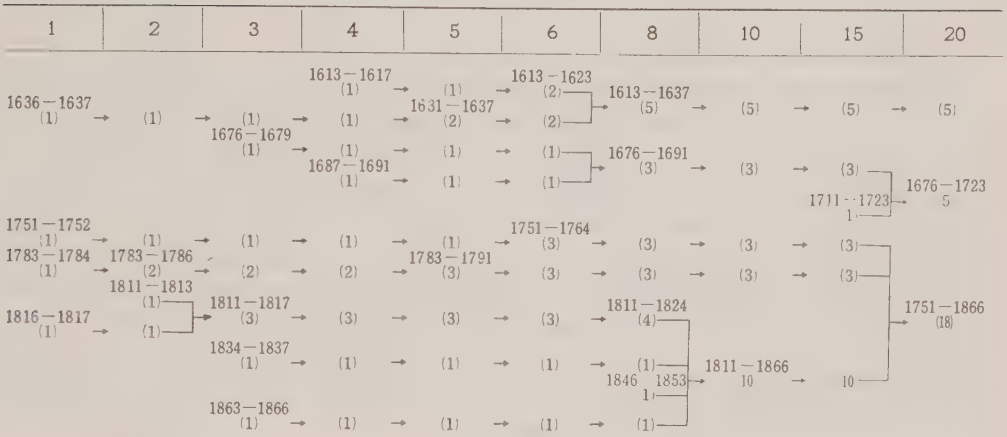



Fig. 53. The deviation of the numbers of the apparent clusters of respective population sizes, in contrast with that of the theoretically estimated numbers of the false clusters, when respective $k$ are set to be the key-lengths to decoding the distribution patterns (Example Y 4).

Table 14. The positions of the apparent clusters and the changes in their features with increase in $k$ (Example Y 4).

| 1 | 2 | 3 | 4 | 5 | 6 | 8 | 10 | 15 | 20 |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | 43−49 (1)<br>56−62 (1) | 43−62 (3) | (3) | (3) | (3) |
| | 111−113 (1) | 108−113 (2) | 104−113 (3) | (3) | (3) | 96−113 (4) | 87−113 (5) | (5) | (5) |
| | 226−228 (1) | 223−228 (2) | 223−232 (3) | (3) | 217−232 (4) | (4) | (4) | 217−246 (5) | (5) |
| 348−349 (1) | (1) | (1) | 348−356 (4) | (4) | (4) | (4) | (4) | (4) | (4) |
| 353−354 (1) | 353−356 (2) | (2) | | | | | | | |
| | | | | | | | | | 388−408 (1) |
| | | | | | | | | 513−527 (1) | (1) |
| | 561−563 (1) | 558−563 (2) | (2) | (2) | 552−563 (3) | 552−583 (7) | | | |
| | 581−583 (1) | 578−583 (2) | (2) | (2) | (2) | | 552−593 (9) | (9) | (9) |
| 592−593 (1) | (1) | (1) | (1) | (1) | (1) | (1) | | | |
| | | | 629−633 (1) | (1) | (1) | (1) | 629−647 (3) | (3) | (3) |
| | | | 643−647 (1) | (1) | (1) | (1) | | | |
| | | 743−746 (1) | (1) | (1) | (1) | (1) | (1) | (1) | (1) |
| 773−774 (1) | (1) | (1) | (1) | (1) | (1) | (1) | 773−783 (2) | (2) | (2) |
| 836−873 (1) | (1) | (1) | 832−837 (2) | (2) | (2) | (2) | (2) | (2) | 816−837 (3) |
| | | 863−866 (1) | (1) | 858−866 (2) | (2) | (2) | (2) | (2) | (2) |
| | 972−974 (1) | (1) | (1) | (1) | (1) | (1) | (1) | (1) | |
| | 1002−1004 (1) | (1) | 1002−1008 (2) | (2) | (2) | 994−1008 (3) | (3) | | |
| | | | | | | | 1022−1032 (1) | | 972−1081 (14) |
| | | | | 1047−1052 (1) | (1) | (1) | | 994−1081 (12) | |
| 1061−1062 (1) | (1) | (1) | (1) | (1) | (1) | (1) | 1047−1062 (3) | | |
| | 1079−1081 (1) | 1076−1081 (2) | (2) | (2) | (2) | (2) | (2) | | |
| | | | 1103−1107 (1) | 1103−1112 (2) | (2) | (2) | (2) | (2) | 1103−1131 (3) |
| 1166−1168 (2) | (2) | 1166−1174 (4) | (4) | (4) | (4) | (4) | (4) | | |
| | | | | 1186−1191 (1) | (1) | (1) | (1) | 1166−1213 (9) | (9) |
| | | | 1209−1213 (1) | (1) | (1) | 1202−1213 (2) | (2) | | |
| 1243−1244 (1) | (1) | 1243−1247 (2) | (2) | (2) | (2) | (2) | (2) | 1243−1259 (3) | (3) |
| 1308−1309 (1) | (1) | 1308−1312 (2) | (2) | (2) | 1308−1318 (3) | (3) | (3) | 1308−1342 (6) | |
| | 1329−1331 (1) | (1) | (1) | (1) | (1) | (1) | (1) | | 1308−1388 (10) |
| | | | | | 1362−1368 (1) | (1) | (1) | 1362−1388 (3) | |
| | | | | 1383−1388 (1) | (1) | (1) | (1) | | |
| 1416−1418 (2) | (2) | 1413−1421 (4) | (4) | (4) | (4) | (4) | (4) | | |
| | | | | 1432−1437 (1) | (1) | (1) | 1432−1447 (3) | 1413−1447 (8) | (8) |
| 1446−1447 (1) | (1) | (1) | (1) | (1) | (1) | (1) | | | |
| | | 1469−1472 (1) | (1) | (1) | (1) | (1) | (1) | 1469−1514 (6) | (6) |
| 1502−1503 (1) | (1) | (1) | (1) | (1) | (1) | (1) | 1502−1514 (3) | | |
| 1513−1514 (1) | (1) | (1) | (1) | (1) | (1) | (1) | | | |
| 1546−1547 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | | | | | | | | | 1571 1587 1 |




ones and a cluster constituted of three hooked-individuals are regarded as the true ones caused by the schooling tendency. But assume that the key-length is two hook-intervals, and six clusters constituted of each two hooked-individuals and two clusters constituted of each one more hooked-individuals are regarded to be the true ones among 22 apparent ones. And four apparent-clusters of large population-size are observable, but they can not be regarded as the true ones, because even if all the individuals are hooked by chance as many as apparent-clusters of such a population-size as this are expected to be observable. And even if two hook-interval width is recognized as the key-length to the elemental-clusters, the individuals derived from the true elemental-clusters reach merely a little more than 1/10 of total catch while the rests of it are the single individuals swimming solitarily or forming the false-clusters expected to occur even if all the individuals are hooked by chance.

*Structure at the second order* ($k = 4$): Even if the key-length is set to be four hook-intervals, one cluster constituted of two hooked-individuals among 23 apparent ones, two clusters of each three hooked-individuals among eight apparent ones, one or two clusters of each four hooked-individuals among three and all or one less cluster of each five hooked-individuals among three apparent ones are recognized as the true ones, which occupy about 18 % of total catch.

*Structure at the third order* ($k = 15$): It seems to be better to regard 15 hook-intervals as the key-length to the structure at the third order. But the observed-value in the interval analysis at $k = 15$ is higher than the neighbouring ones, although it does not exceed corresponding theoretical one, moreover, observed-value at $k = 9$ is a little higher than the neighbouring ones and this bears some characteristics of peak, and also these two key-lengths, four and 15 hook-intervals, are too apart from each other; therefore, it is necessary to examine on the change in the features of the cluster-formation with increase in key-length from four to 15 hook-intervals. But I found that no conspicuous change in the features of the cluster-formation was observable around $k = 9$ except a sudden decrease in the observed number of the

clusters constituted of two hooked-individuals against the gradual decrease in the theoretical-value, although the clusters constituted of more than six hooked-individuals come to appear when $k$ exceeds six hook-intervals.

And at last when key-length is elongated into 15 hook-intervals, the population gets to show such a pattern as mentioned below: the aggregative tendency of the shorter intervals —— *i. e.*, the schooling tendency —— decreases the actually observed numbers of the clusters constituted of a single or one more interval till they do not reach the numbers expected in the chance distribution, meanwhile increases the actually observed numbers of the clusters constituted of more than seven hooked-individuals till they exceed the theoretical numbers representing the expectant numbers from the chance distribution. Consequently, some clusters capable of being regarded as the true ones come to be observable; they are two clusters constituted of each 10 or one more hooked-individuals among three apparent ones and a cluster of 13 hooked-individuals. Thus, about 1/5 of total catch distributed within 1/10 of a row is thought to form three clusters.

*Structure at the highest order* ($k = 20$): It may well be said that the fourth peak of the observed-values in the interval analysis is found at $k = 20$, although both the observed-values and the estimated ones in the interval analysis in the range $k > 11$ do not reach five, therefore, I am afraid that the guessing of the key-length is severely suffered from the influence of accidental error. And the structure at this step is, for convenience' sake, called the structure at the highest order observable within a row, the details of which will be described below.

The low observed-values and the estimated ones do not allow me to describe no fact else than that at least three clusters constituted of as many as or more than 10 hooked-individuals among five apparent ones are able to be regarded as the true-clusters due to the schooling tendency. And that constituted of 19 hooked-individuals covering the part from the first hook in the 351th basket (H.N. 1751) to the hook of the same order spaced by 23 baskets (H.N. 1866), that of 15 hooked-individuals covering the part from the second hook in the 195th basket (H.N. 972) to the first hook in the 217 th basket (H.N. 1081) and that of 10 hooked-individuals covering the part from the second hook in the 111th basket (H.N. 552) to the third hook in the 119th basket (H.N. 593) are the most probable to be the true ones. Accordingly, about 1/3 of catch distributed within 1/7 of a row is thought to form three small schools.

### Example Y 5

For decoding of such an example showing a strong gradient as this, we must keep in mind the fact that the influence of the gradient is not yet excluded from the theoretical-values in the arrangement analysis and also the exclusion of this influence from the theoretical-values in the interval analysis is very hard, consequently the strong gradient is inclined to decrease slightly the theoretical numbers of the clusters of small population-size, meanwhile to increase slightly those constituted of many hooked-individuals, moreover it is also inclined to biase the hooked positions of the larger

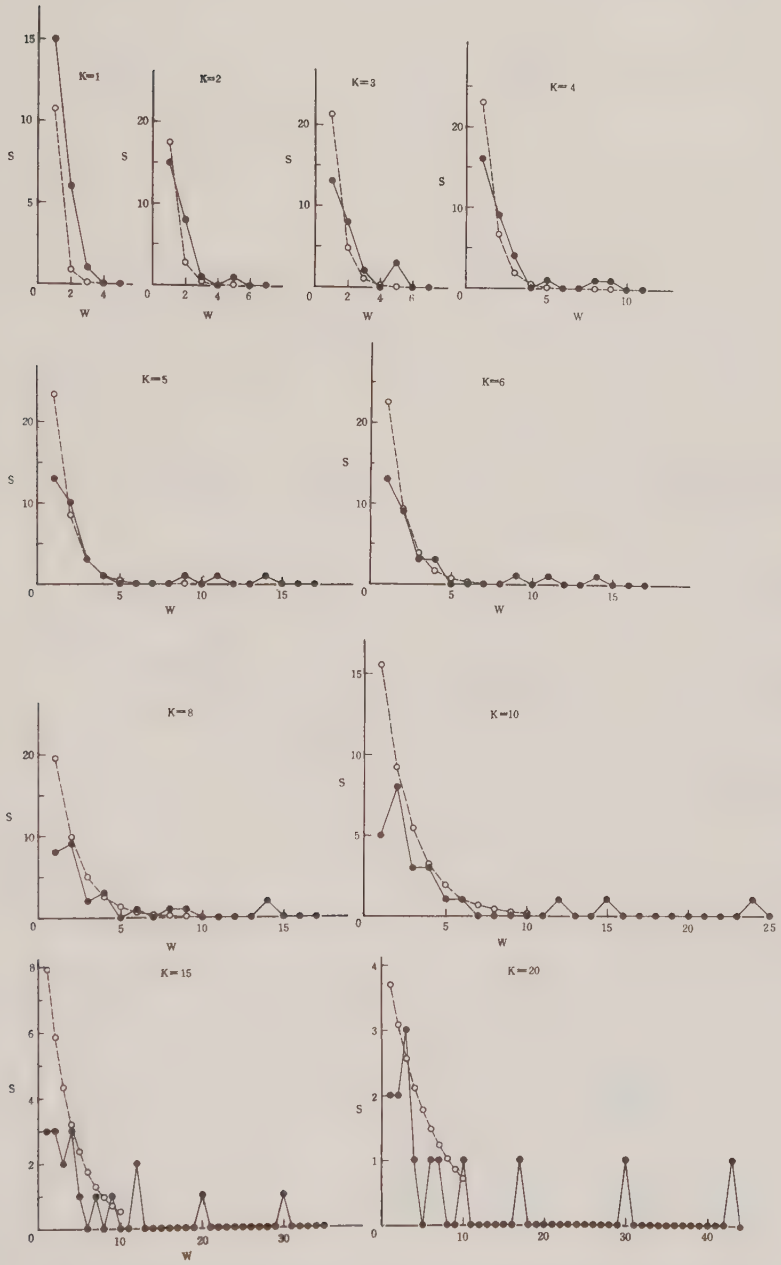



Fig. 54. The deviation of the numbers of the apparent clusters of respective population sizes, in contrast with that of the theoretically estimated numbers of the false clusters, when respective $k$ are set to be the key-length to decoding the distribution patterns (Example Y 5 ).

Table 15. The positions of the apparent clusters and the changes in their features with increase in $k$ (Example Y 5).

| 1 | 2 | 3 | 4 | 5 | 6 | 8 | 10 | 15 | 20 |
|---|---|---|---|---|---|---|---|---|---|
| 481−483 (2) | → (2) | → (2) | → 477−483 (3) | → 472−483 (4) | → (4) | → (4) | → 472−493 (5) | → (5) | → 472−512 (6) |
| | | | 592−596 (1) | → (1) | → (1) | → (1) | → 582−596 (2) | → (2) | → (2) |
| | | | | 617−622 (1) | → (1) | → (1) | → (1) | → (1) | → (1) |
| 848−849 (1) | → (1) | → (1) | → (1) | → (1) | → (1) | → 833−849 (3) | → (3) | → (3) | → (3) |
| | | | | | | | | 912−923 1 | → 1 |
| 951−952 (1) | → (1) | → (1) | → 947−952 (2) | → (2) | → (2) | → (2) | → (2) | → (2) | |
| | | | 988−992 (1) | → (1) | → 988−998 (2) | → (2) | → 968−977 (2) | → 968−1021 (7) | → 947−1021 (10) |
| | 1019−1021 1 | → 1 | → 1 | → 1 | → 1 | → 1011−1021 2 | → 2 | | |
| 1136−1137 1 | → 1 | → 1133−1137 (2) | → 1133−1141 3 | → 3 | → 1127−1141 4 | → 4 | → 4 | → 4 | → 1077−1141 7 |
| | | | | | | | | 1171−1222 (4) | → (4) |
| 1252−1253 (1) | → (1) | → 1252−1256 (2) | → (2) | → (2) | → (2) | → (2) | → (2) | → (2) | → (2) |
| | | | 1278−1282 (1) | → (1) | → (1) | → (1) | → 1278−1294 (3) | → (3) | → (3) |
| | | 1291−1294 (1) | → (1) | → (1) | → (1) | → (1) | | | |
| 1323−1324 (1) | 1323−1326 (2) | → (2) | → (2) | → (2) | → 1323−1332 (3) | | | | |
| | | | 1339−1343 1 | → (1) | → (1) | → 1323−1359 (8) | | | |
| 1351−1352 (1) | → (1) | → (1) | → (1) | → (1) | → (1) | | → 1323−1377 (12) | → (12) | → 1323−1411 (17) |
| 1368−1369 (1) | 1368−1371 (2) | → (2) | → (2) | → (2) | → 1368−1377 (3) | → (3) | | | |
| 1393−1394 (1) | → (1) | → (1) | → (1) | → (1) | → (1) | → (1) | → 1393−1411 (4) | → (4) | |
| | | | 1403−1411 (2) | → (2) | → (2) | → (2) | | | |
| 1478−1479 (1) | → (1) | → (1) | → (2) | → 1478−1483 (3) | → 1473−1483 (4) | → 1467−1483 (1) | | | |
| | | | | | 1491−1497 (1) | → 1467−1497 (6) | → (6) | → 1454−1513 (9) | |
| | 1511−1513 (1) | → (1) | → (1) | → (1) | → (1) | → (1) | → (1) | | → 1454−1616 (30) |
| 1557−1558 (1) | → (1) | → (1) | → 1557−1563 (3) | | | | | | |
| 1562−1563 (1) | → (1) | → (1) | | | | | | | |
| 1571−1573 (2) | → (2) | → 1568−1573 (3) | → 1568−1584 (9) | → 1552−1584 (14) | → (14) | → (14) | → 1543−1584 (15) | → 1532−1616 (20) | |
| 1581−1584 (3) | 1577−1584 (5) | → (5) | | | | | | | |
| | 1611−1613 (1) | → 1611−1616 (2) | → (2) | → (2) | → (2) | → (2) | → 2 | | |
| | | | 1638−1642 (1) | → (1) | → (1) | → (1) | → 1 | | |
| | | | 1657−1661 (1) | → 1657−1666 (2) | → (2) | | | | |
| 1673−1674 (1) | → (1) | → (1) | → 1673−1678 2 | | | | | | |
| 1683−1684 (1) | → (1) | → 1683−1687 (2) | → 1683−1698 (8) | → 1673−1698 (11) | → (11) | → 1657−1698 (14) | | | |
| 1691−1693 (2) | → (2) | → 1691−1698 (5) | | | | | | | |
| 1696−1698 (2) | → 2 | | | | | | → 1657−1736 (24) | → 1638−1758 (30) | |
| | | | 1708−1712 (1) | → 1708−1736 (9) | → (9) | → (9) | | | |
| 1727−1729 (2) | → (2) | → 1727−1736 (5) | → (5) | | | | | | |
| 1732−1733 (1) | → (1) | | | | | | | | |
| 1747−1749 (2) | → (2) | → (2) | → (2) | → (2) | → (2) | → (2) | → 1747−1758 (3) | | → 1638−1847 (43) |
| | | 1778−1781 (1) | → (1) | → (1) | → (1) | → (1) | → 1 | | |
| 1801−1802 (1) | 1799−1804 (3) | → (3) | → (3) | → (3) | → (3) | → 1792−1804 (4) | → (4) | → 1778−1847 (12) | |
| | | 1823−1826 (1) | → (1) | → 1818−1826 (2) | → (2) | → (2) | → 2 | | |
| | | | 1838−1842 (1) | → 1838−1847 (2) | → (2) | → (2) | → 2 | | |

apparent-clusters observable the more frequently with approach to the end of hauling. In company with these, the low observed-values and the estimated ones in the interval analysis do not allow me to find out any key-length longer than six hook-intervals somewhat rid of the severe influence of accidental error. Accordingly, I do not wish to describe any further pattern but that represented below.

*Structure at the elemental step* ($k=1$) : Even if putting the influence of the strong gradient out of consideration, I can not find out any fact but that 10 clusters——which are four clusters constituted of each two hooked-individuals among 15 apparent ones, five clusters of each three hooked-individuals among six apparent ones and a basket fully occupied——may be as if the true ones. But, for the purpose of guessing out which apparent-clusters are the true ones, we must consider together with their hooked positions. But no fact is deducible other than that the influence of the gradient is very strong, because all the apparent-clusters, except two constituted of not so many hooked-individuals, are caught in the latter half of hauling of a row, especially densely in the last quarter.

*Structure at the second order* ($k=4$) : To the distribution pattern at this step, generally speaking, no fact can be deduced other than that the individuals are hooked showing a strong gradient. That is to say, the deviation of the observed-values in the arrangement analysis seems to show as if there are three true cluster-like aggregations constituted of 6 , 9 and 10 hooked-individuals respectively, besides two of those constituted of each three hooked-individuals and the same number of those of four hooked-individuals; but when we take the influence of the strong gradient into consideration, whether each of them is recognizable as the true one or not becomes highly doubtful, because all of these larger clusters are hooked in the last 1/7 of hauling of a row; moreover, even all other apparent-clusters, except three, are also hooked in the latter half of hauling of a row, which suggest that the presence of even the smaller clusters is also doubtful.

*Structure at the higher orders* : The low observed-values and the estimated ones in the interval analysis make it impossible to guess out any key-length to the higher orders; accordingly, it is impossible to continue discussing the structures at the higher orders somewhat rid of the influence of accidental error introduced into the guessing of the key-length. Accordingly, the key-length increased step by step, the changes in the features of the true cluster-like aggregations are discussed; then the influence of the strong gradient considered together with their hooked positions, whether they can be regarded as the true ones or not is examined. But, here, none of the apparent-clusters, except those mentioned in the preceding step as the larger ones, can be regarded as the true cluster-like aggregation, consequently there is no need to give any further description.

And we will easily notice that, when $k$ does not exceed six hook-intervals, there is no true cluster-like aggregation hooked in the other part in a row than the last 1/7 of hauling; and even if the key-length is elongated into as long as 20 hook-intervals, all the true cluster-like aggregations are hooked successively from the last hook of the hauling of a row to the third hook in the 265th basket (H.N. 1323).

Accordingly, no fact is deducible from the results except that the individuals are distributed showing a strong gradient.

But before closing the discussion on the pattern observable in such a example as this in which a strong gradient is suspected, further attention should be paid to another factor newly closed up——the hooked positions of respective lots relating to their population-size, because it is more probable that the apparent-clusters constituted of a little many hooked-individuals and found in the earlier part of hauling have to be regarded as the true-clusters due to the schooling tendency, even if the observed numbers in the arrangement analysis do not reach corresponding theoretical ones. Therefore, it seems to be better to regard that the following four apparent-clusters may be caused by the schooling tendency and should be regarded as the true-schools; they are respectively the cluster constituted of seven hooked-individuals and covering the part from the second hook in the 95th basket (H.N. 472) to the hook of the same order spaced by eight baskets (H.N. 512), that of 11 hooked-individuals and covering the part from the second hook in the 190th basket (H. N. 947) to the first hook in the 205th one (H.N. 1021) and that of eight hooked-individuals and covering the part from the second hook in the 216th basket (H.N. 1077) to the first hook in the 229th basket (H.N. 1141).

**Example Y 6**

In contrast with the preceding example, the influence of the gradient of distribution seems to be as weak as negligible.

*Structure at the elemental step* ($k = 1$): The following pattern is deducible from Fig. 55—(1) as the structure at the elemental step, in which one hook-interval is adopted as the key-length: nineteen clusters —— which are 10 clusters constituted of each two individuals hooked successively among 35 apparent ones and nine ones constituted of one more individuals among 12 apparent ones——are recognized as the true-clusters; and, of course, a basket fully occupied is also thought to be the true one. Therefore, one fifth of catch is thought to be derived from 20 elemental-clusters mingling with single individuals which occupy 4/5 of catch; but the hooked positions of the clusters, except the largest one, are uncertain because of the difficulty in distinguishing the true-clusters from the false ones, although all the hooked positions of the apparent-clusters are illustrated in Table 16.

*Structure at the second order* ($k=3$): The second peak of the observed-values in the interval analysis is found at $k = 3$. Accordingly, the following structure is found out, when we adopt three hook-intervals as the key-length. The schooling tendency of the individuals lets decrease the number of the lots of small population-size meanwhile increase those of the large population-size; thus the single isolated-intervals do not so frequently observable as the expectant number from the chance distribution, against the fact the intervals as long as or shorter than three hook-intervals are more frequently observable than expected from the chance distribution; while three more lots each of which is constituted of two intervals arranged successively, two more lots of three intervals and one more lot of four intervals and each two more lots

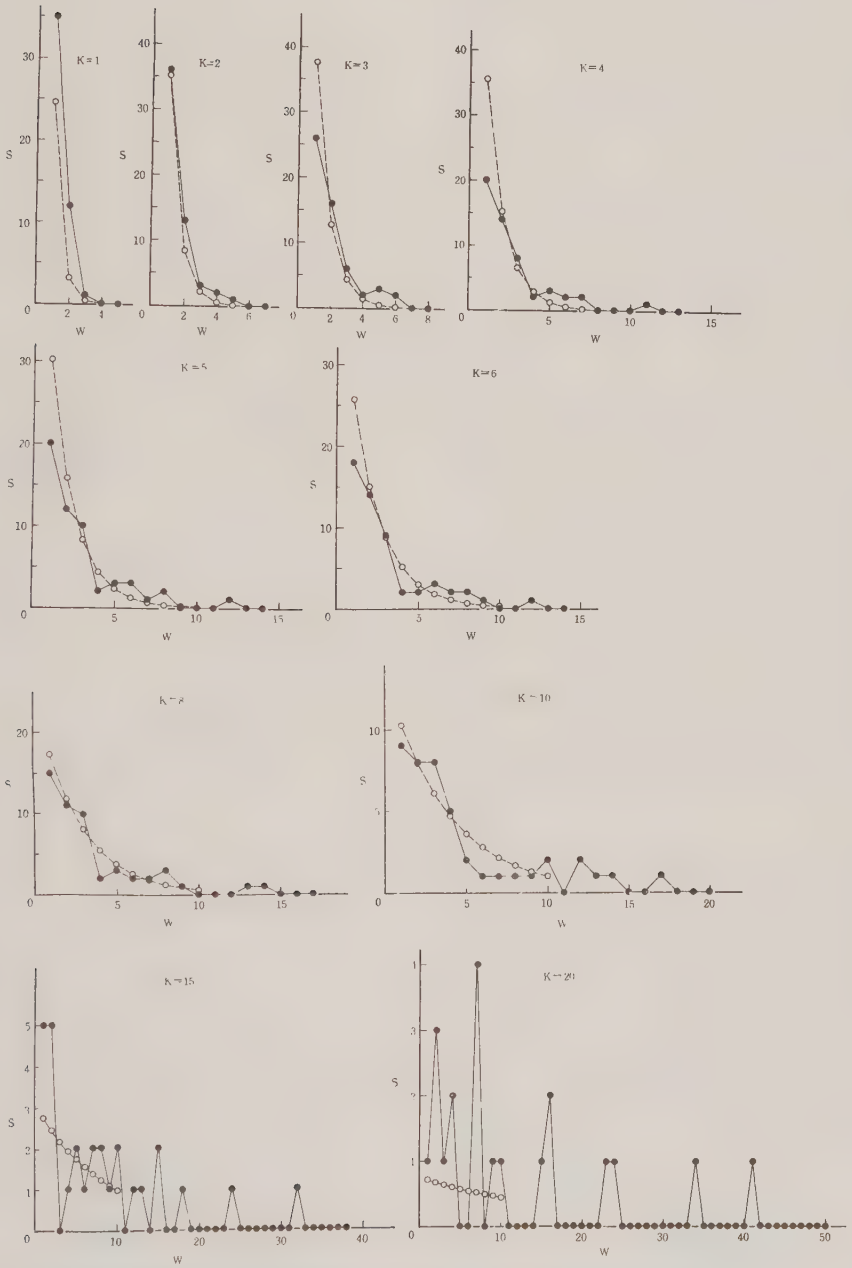
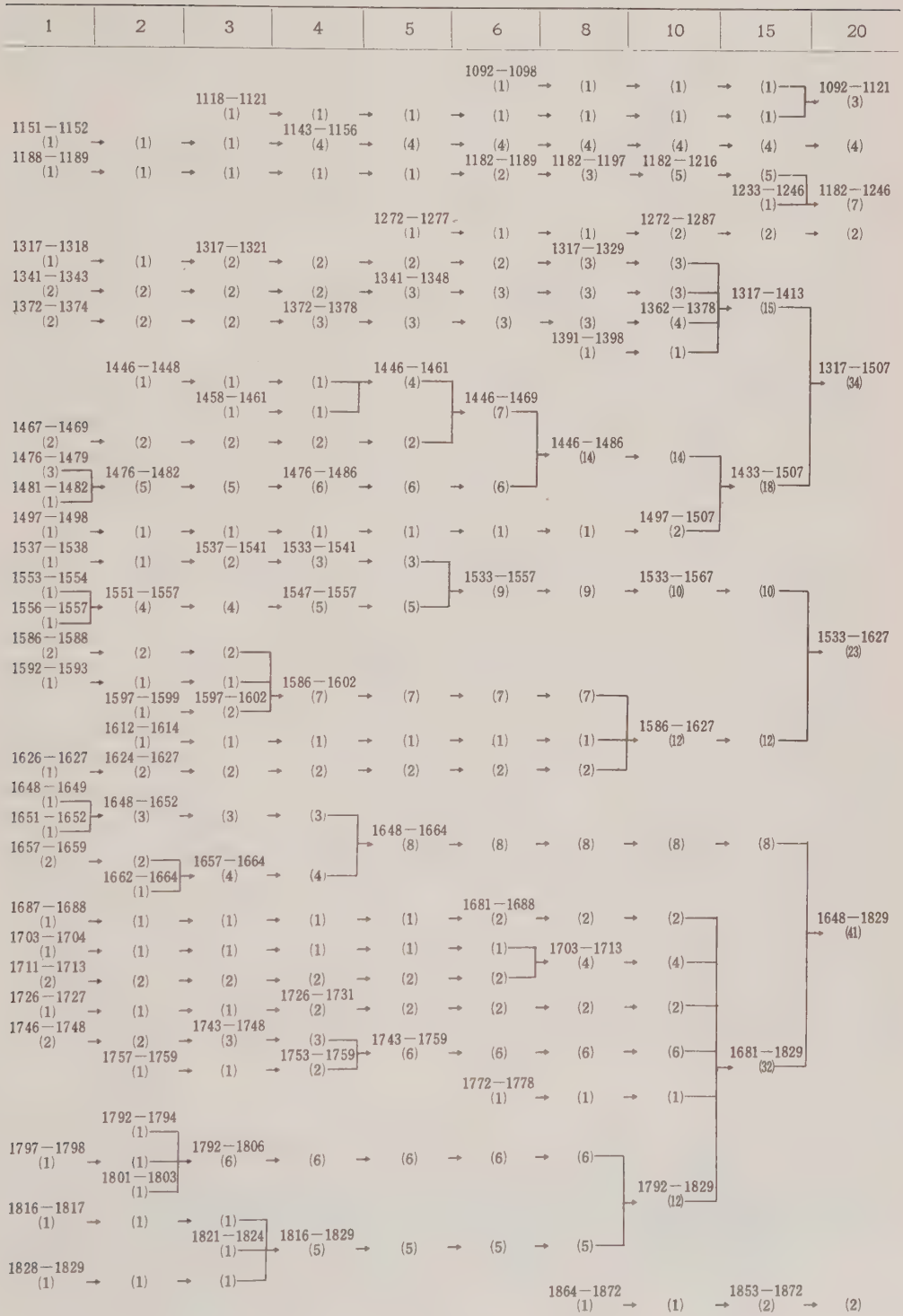



Fig. 55. The deviation of the numbers of the apparent clusters of respective population sizes, in contrast with that of the theoretically estimated numbers of the false clusters, when respective $k$ are set to be the key-lengths to decoding the distribution patterns (Example Y 6 ).

Table 16. The positions of the apparent clusters and the changes in their features with increase in $k$ (Example Y 6).

| 1 | 2 | 3 | 4 | 5 | 6 | 8 | 10 | 15 | 20 |
|---|---|---|---|---|---|---|---|---|---|
| 36−38 (2) | (2) | (2) | 14−18 (1) → (2) | 14−23 (2) → (3) | (2) → (3) | 14−46 (7) | (7) | (7) | 14−111 (16) |
| 66−67 (1) | (1) | (1) | 62−67 (2) | 31−38 (3) → 62−72 (3) | (3) | (3) | 62−81 (4) | 62−111 (8) | |
| | | | | 106−111 (1) | (1) | 92−111 (3) | (3) | | |
| 137−138 (1) | (1) | 137−141 (2) | (2) | (2) | (2) | (2) | (2) | (2) | (2) |
| | 187−189 (1) | (1) | (1) | (1) | (1) | (1) | 168−189 (3) | | |
| | | | | | | | 201−211 (1) | 168−237 (9) | (9) |
| 231−232 (1) | (1) | (1) | (1) | 226−237 (3) | (3) | (3) | (3) | | |
| | | | | 258−263 (1) | (1) | (1) | (1) | (1) | 258− 303 (7) |
| 288−289 (1) | (1) | (1) | (1) | (1) | 282−289 (2) | (2) | 282− 303 (5) | (5) | |
| | 299−303 (2) | (2) | (2) | (2) | (2) | (2) | | | |
| | | 241−247 (2) | (2) | (2) | (2) | (2) | (2) | (2) | 341−374 (4) |
| | | 414−417 (1) | (1) | (1) | (1) | (1) | | 363−374 (1) | |
| 436−438 (2) | (2) | | | | | | 414− 447 (10) | (10) | (10) |
| | 441−443 (1) | 436−447 (6) | 432−447 (7) | 427−447 (8) | (8) | (8) | | | |
| 446−447 (1) | (1) | | | | | | | | |
| 511−512 (1) | 511−514 (2) | 508−514 (3) | (3) | (3) | (3) | 508−533 (8) | | | |
| 521−523 (2) | (2) | (2) | 521−527 (3) | (3) | 521−533 (4) | | | | |
| 551−552 (1) | (1) | (1) | (1) | (1) | (1) | (1) | | | |
| 562−563 (1) | (1) | 562−568 (3) | | | | | 508−573 (17) | | |
| | 566−568 (1) | | 562−573 (5) | (5) | (5) | (5) | | 483−617 (24) | (24) |
| 572−573 (1) | (1) | (1) | | | | | | | |
| | | | | 586−591 (1) | | | | | |
| | | | | 597−602 (1) | 586−602 (3) | (3) | (3) | | |
| 658−659 (1) | 654−659 (3) | 648−659 (5) | | | | | | | |
| 663−664 (1) | 663−668 (4) | 663−671 (5) | 648−671 (11) | 648−676 (12) | (12) | 641−676 (13) | (13) | (13) | 641−697 (16) |
| 666−668 (2) | | | | | | | | | |
| 696−697 (1) | (1) | 693−697 (2) | (2) | (2) | (2) | (2) | (2) | (2) | |
| | | | | | | | | | 728−747 (1) |
| 787−788 (1) | (1) | (1) | (1) | 787−793 (2) | (2) | (2) | (2) | 773−818 (7) | (7) |
| 817−818 (1) | (1) | 814−818 (2) | (2) | (2) | (2) | 806−818 (3) | (3) | | |
| 866−867 (1) | (1) | (1) | (1) | (1) | (1) | (1) | (1) | | |
| 887−888 (1) | (1) | (1) | (1) | (1) | (1) | 879−888 (2) | 879−901 (4) | 866−901 (6) | 849−901 (7) |
| | | | 897−901 (1) | (1) | (1) | (1) | | | |
| | | 941−944 (1) | (1) | (1) | (1) | 941−951 (2) | 931−951 (3) | | |
| 966−968 (2) | 964−968 (3) | (3) | (3) | (3) | (3) | (3) | | | |
| 977−978 (1) | (1) | 977−984 (3) | (3) | (3) | (3) | 977−997 (5) | 964−997 (9) | 931−1013 (15) | (15) |
| | | | | 992−997 (1) | (1) | | | | |
| | | | 1009−1013 (1) | (1) | (1) | (1) | (1) | | |


1
2
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1092—1098
1092—1121
1118—1121
1151—1152
1143—1156
1188—1189
1182—1189
1182—1197
1182—1216
1233—1246
1182—1246
1272—1277
1272—1287
1317—1318
1317—1321
1317—1329
1341—1343
1341—1348
1317—1413
1372—1374
1372—1378
1362—1378
1391—1398
1446—1448
1446—1461
1317—1507
1458—1461
1446—1469
1467—1469
1446—1486
1476—1479
1476—1482
1476—1486
1433—1507
1481—1482
1497—1498
1497—1507
1537—1538
1537—1541
1533—1541
1553—1554
1533—1557
1533—1567
1551—1557
1547—1557
1556—1557
1533—1627
1586—1588
1592—1593
1586—1602
1597—1599
1597—1602
1612—1614
1586—1627
1626—1627
1624—1627
1648—1649
1648—1652
1651—1652
1648—1664
1657—1659
1657—1664
1662—1664
1687—1688
1681—1688
1648—1829
1703—1704
1703—1713
1711—1713
1726—1727
1726—1731
1746—1748
1743—1748
1743—1759
1757—1759
1753—1759
1681—1829
1772—1778
1792—1794
1797—1798
1792—1806
1801—1803
1792—1829
1816—1817
1821—1824
1816—1829
1828—1829
1864—1872
1853—1872

of 5 and 6 successively arranged intervals are observable; these are all thought to reflect on the schooling tendency and should be regarded as the true-clusters. But their hooked positions are uncertain because of the same reason as mentioned above. And the catch from these 10 clusters occupies 1/5 of total catch.

*Structure at the higher orders* : The observed-values in the interval analysis at $k = 10$, 13, 17 and 19 hook-intervals seem to exceed the theoretical ones; this fact suggests that these may be the key-lengths to the higher orders. But all the observed-values and the estimated ones in the interval analysis in the range $k > 15$ hook-intervals do not reach five. Therefore, if we want to find out the pattern somewhat rid of the influence of accidental error introduced into the key-length, we can not give any further consideration to the structure of the higher orders than the third. Accordingly, the distribution pattern, when 10 hook-interval width is adopted as the hypothetical key-length, will be explained; then a short description of the structure, in which the hypothetical key-length is set to be 15 hook-intervals, and appendantly with that at 20 hook-intervals, will be added, for reference' sake.

(*Structure at the third order*)——Among many apparent-clusters of small population-size, only two clusters constituted of each four hooked-individuals are capable of being regarded as the true-clusters due to the schooling tendency. Besides them, it is also suggested that, among eight apparent-clusters constituted of each as many as or more than 10 hooked-individuals, at least some of them may be the true ones. But the hooked positions, moreover even the number, of these true-clusters are uncertain.

(*Structure at the higher orders*)——When the key-length is elongated into as long as 15 hook-intervals, total number of the lots can not be more than 30, which is thought to be not so many enough, because the intervals longer than 15 hook-intervals are only as many as 28 among 253 intervals. Moreover, these 30 or less lots are classified into the groups according to their population-size showing a slight decrease with increase in their population-size; accordingly, not only the theoretical numbers of the lots of respective population-size but also the observed ones become very few. And these facts make it difficult to deduce any fact but that the presence of some clusters of large population-size is suspected; and their hooked positions and the population-sizes are easily estimative from Table 16. But even if dare to say committing against the presupposable severe-influence of accidental error, no further fact is guessed out except that these probable schools are rather dispersively distributed. These tendencies become far influential when the key-length is elongated into as long as 20 hook-intervals.

### Example Y 7

It is one of the characteristics of the distribution pattern of this example that the lots constituted of many intervals arranged successively are rather frequently observable, although this fact seems to be partly indebted to the gradient of the distribution. When we regard two hook-intervals as the key-length to the elemental step, four as that to the second order, six or eight as that to the third order, 15 as that to the fourth order and 20 as that to the fifth order respectively, the following

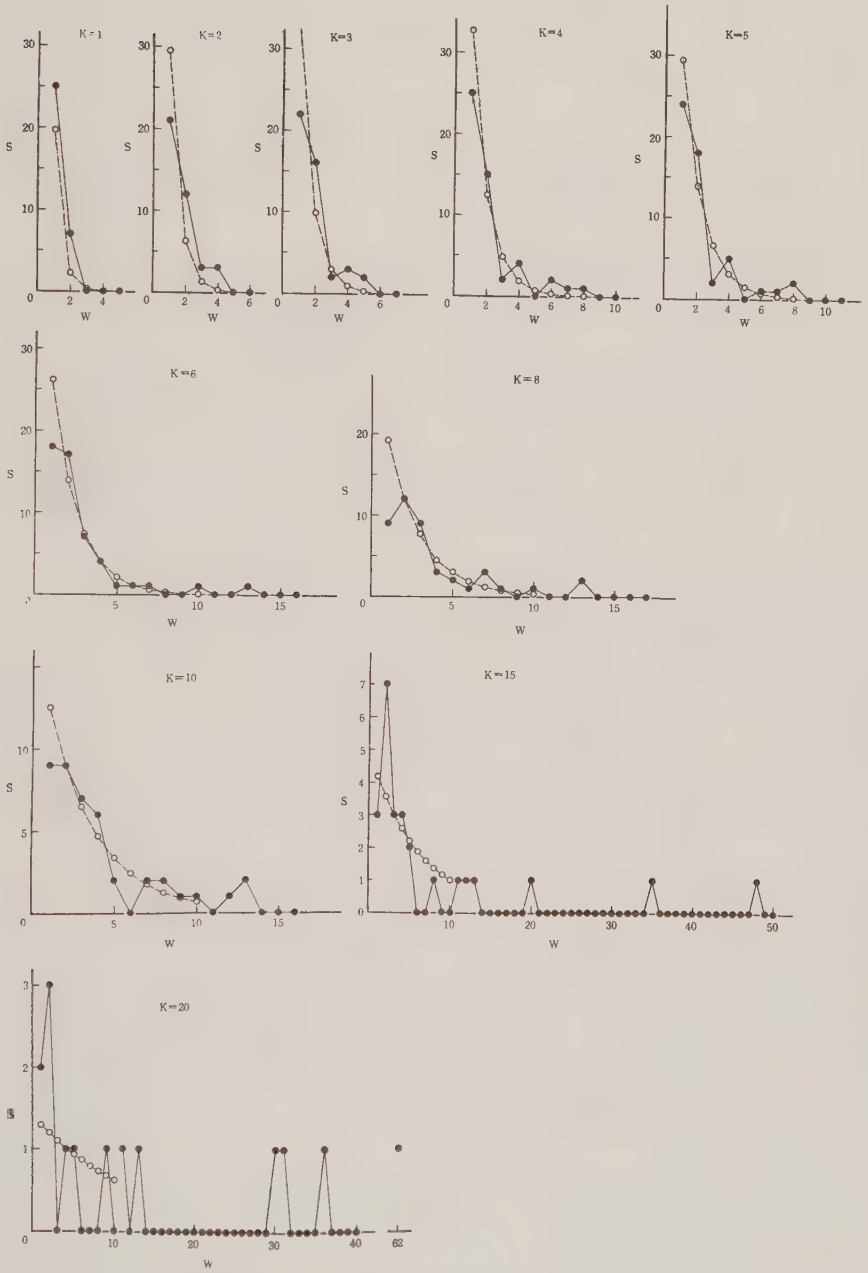
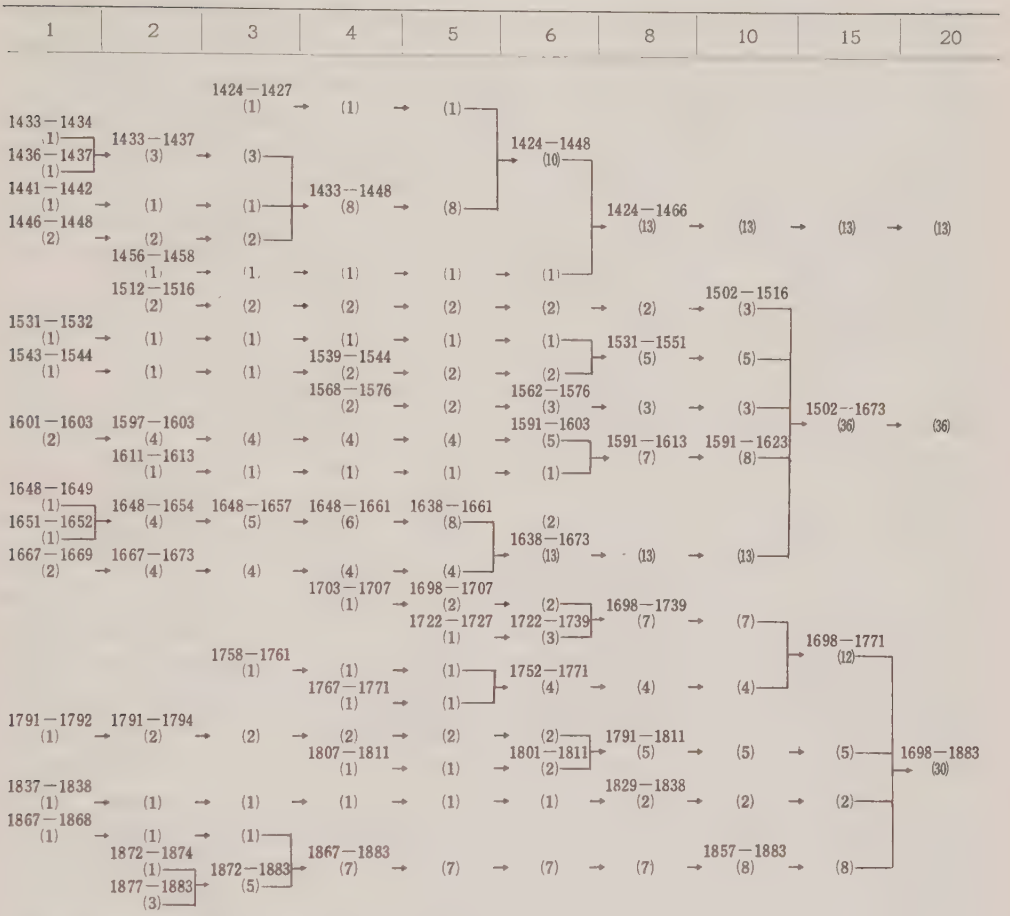



Fig. 56. The deviation of the numbers of the apparent clusters of respective population sizes, in contrast with that of the theoretically estimated numbers of the false clusters, when respective $k$ are set to be the key-lengths to decoding the distribution patterns (Example Y 7 ).

Table 17. The positions of the apparent clusters and the changes in their features with increase in $k$ (Example Y 7).

| 1 | 2 | 3 | 4 | 5 | 6 | 8 | 10 | 15 | 20 |
|---|---|---|---|---|---|---|---|---|---|
| 261−262 (1) | 259−262 (2) | | 237−241 (1) | 169−178 (3) | 127−139 (2) | 63−71 (1) | (1) | (1) | (1) |
| 293−294 (1) | 169−173 (2) | | | | | | | 112−139 (3) | 92−178 (9) |
| | | | | | | | 159−178 (4) | (4) | |
| | | | | | | | | 222−241 (2) | 222−262 5 |
| | | | | | | | | (2) | |
| | | | | | | | | 288−312 (4) | (4) |
| | | | 308−312 (1) | | | | | | |
| 426−427 (1) | | 398−401 (1) | | | | | | 383−401 (2) | (2) |
| | | | | | | | | | |
| 581−582 (1) | | | 481−484 .1 | 481−488 (2) | | | | (1) | (1) |
| | | | | | | | | (2) | (2) |
| | | | | | | | 572−582 (2) | (2) | (2) |
| | | | | 638−643 (1) | | 631−643 (2) | | 631−654 (3) | |
| | | | | | | | 687−696 1) | 673−696 (2) | |
| | | | | | | | | 714−729 1) | |
| | | | 759−767 (2) | | | | | 747−781 (4) | |
| 806−808 (2) | | 806−811 (3) | | 801−811 (4) | | | | | |
| 832−834 (2) | | | | | | 832−842 (3) | 823−842 (4) | | |
| | | 853−856 (1) | | | | | | | 631−1081 (62) |
| 876−877 (1) | 874−877 (2) | | | | 868−877 (3) | | | | |
| 893−894 (1) | | | | | 882−894 (2) | | 868−924 (12) | | |
| 901−902 (1) | | | | | | 887−924 (8) | | | |
| 923−924 (1) | | | | | | | | | |
| | | 946−949 (1) | | 946−954 (2) | | 946−961 (3) | 937−961 (4) | 801−1081 (48) | |
| 993−994 (1) | | 993−997 (2) | | | | | | | |
| 1007−1008 (1) | | | | | | | 974−1022 (9) | | |
| | 1017−1019 (1) | 1017−1022 (2) | | | | | | | |
| 1037−1038 (1) | | 1037−1041 (2) | | | 1037−1047 (3) | | | | |
| | 1061−1063 (1) | | | | | | | | |
| 1078−1079 (1) | 1078−1081 (2) | | | | | | | | |
| 1112−1113 1) | | 1109−1113 2) | 2 | 2 | 1103−1113 3 | 3 | 3 | 3 | |
| 1162−1164 (2) | | | 1162−1169 (4) | | | | | 1151−1169 (5) | |
| 1168−1169 (1) | | | | | | | | | 1103−1306 (31) |
| 1187−1189 (2) | | | 1187−1201 (6) | | | 1187−1229 (10) | | | |
| | 1197−1201 (2) | | | | | | | | |
| | | | 1209−1213 (1) | | | | | | |
| | | 1241−1247 (2) | 1241−1251 (3) | | | | | 1187−1306 20) | |
| | | | | | | | 1263 1272 1 | | |
| | | | | 1287−1297 2) | | | 1287−1306 (3) | | |
| | | | 1328−1332 .1) | | | 1328−1346 (3) | | | |
| 1373−1374 (1) | 1369−1374 (3) | 1369−1377 (4) | | | | | | 1328−1388 (11) | (11) |
| | | | 1384−1388 (1) | | | 1369−1388 (6) | 1359−1388 (7) | | |




structures at respective steps will be guessed out.

*Structure at the elemental step* ($k=2$) : From Fig. 56 —(2), it becomes clear that, on account of the schooling tendency and of the gradient, some of the lots expected to be observable as single or not so many intervals arranged successively are attached to some other intervals; consequently, the single isolated-intervals are actually observable only 2/3 times as frequently as expected from the chance distribution, in contrast with the fact that the lots constituted of two or three intervals arranged successively are observable two times as frequently as expected, moreover three lots of each four intervals are observable. And even if a part of them may be indebted to the gradient, most of them are well thought to be the true-clusters at the elemental step due to the schooling tendency. Therefore, a little more than 4/5 of total catch are thought to be brought from single individuals hooked solitarily or forming the false-clusters caused even by the chance distribution.

*Structure at the second order* ($k=4$) : Besides some clusters of small population-size —— significance of which is somewhat doubtful and they may be probable to be due to accidental error in the chance distribution ——, there are four true cluster-like

aggregations constituted of from seven to nine hooked-individuals and each aggregation is thought to be chiefly constituted of some elemental-clusters to which some single-individuals are attached. But their hooked positions suggest that it seems to be more probable to consider some of even these clusters are not the true ones due to the schooling tendency, but are the false ones indebted to the gradient; while among the apparent-clusters of small population-size, some of those at least hooked in the beginning half of hauling of a row may be neither due to the chance distribution nor to the gradient, but are well thought to be caused by the schooling tendency and have to be regarded as the true-clusters.

*Consideration upon the structure, in which eight hook-interval width is set to be the key-length* : The fact, whether this length can be regarded as one of the key-lengths or not, is somewhat doubtful. Moreover even if we examine on the structure at this step in detail, no fact other than the same one described in the preceding step can be deduced, which seems to mean that this length can not be one of the key-lengths.

*Structure at the third order* ($k = 15$) : The number of the intervals longer than 15 hook-intervals is no more than 30 among 223 total ones; thus total number of the lots is not so many; moreover the scarcity of the lots of each population-size is emphasized by the gradual decrease in both the observed numbers and the estimated ones of the lots with increase in their population-size. Accordingly, I am afraid that the arrangement analysis is severely suffered from the influence of accidental error. But, in any case, the presence of three clusters constituted of 21, 36 and 49 hooked-individuals respectively may well be regarded to be caused by the schooling tendency, because of the fact that their hooked positions are not so strongly restricted to the latter half of the hauling of a row. But their schooling tendency is thought to be not so strong, because, in contrast with the fact that they cover 1/3 as wide as total length of a row, catch does not attain to as many as a half of total one.

*Structure at the highest order* ($k = 20$) : The intervals longer than 20 hook-intervals are no more than 1/10 of total one; accordingly, the structure at this step may be thought to be that of the highest order observable within a row. The observed numbers of the lots of respective population-sizes and the estimated ones become far less than those in the preceding step; this makes it far more difficult to decode the pattern rid of the severe influence of accidental error. But it may well be considered that at least two, frequently all three schools constituted of each a little more than 30 hooked-individuals among three apparent ones are regarded to be the true-schools caused by the schooling tendency and, of course, that constituted of 63 hooked-individuals is also the true one. Thus, the same but clearer pattern as that of the preceding step can be deduced. And even if one were result of the chance distribution or accidental error in the arrangement analysis, about a little more than a half of total catch distributed within a little narrower width than a half of a row forms three schools of weak contagiousness, the adjacent centers of which are spaced by a width as long as 80 baskets from each other.

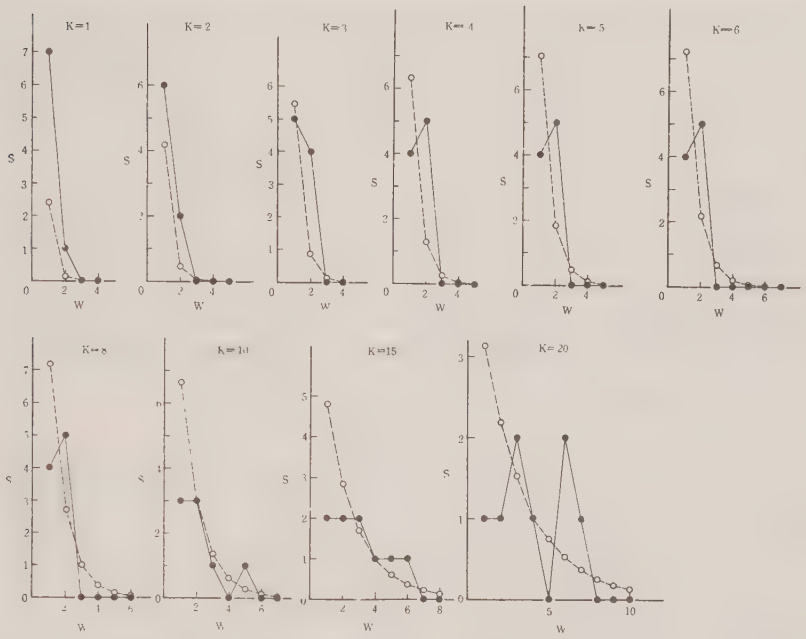



Fig. 57. The deviation of the numbers of the apparent clusters of respective population sizes, in contrast with that of the theoretically estimated numbers of the false clusters, when respective $k$ are set to be the key-lengths to decoding the distribution patterns (Example Y 8).

Table 18. The positions of the apparent clusters and the changes in their features with increase in $k$ (Example Y 8).

| 1 | 2 | 3 | 4 | 5 | 6 | 8 | 10 | 15 | 20 |
|---|---|---|---|---|---|---|---|---|---|
| 98−99 (1) | → (1) | → 98−102 (2) | → (2) | → (2) | → (2) | → (2) | → 98−112 (3) | → (3) | → (3) |
| 181−183 2 | → (2) | → (2) | → (2) | → (2) | → (2) | → (2) | → (2) | → (2) | → 181−203 (3) |
| | | 358−361 1) | → (1) | → (1) | → (1) | → (1) | → (1) | → (1) | → (1) |
| 398−399 (1) | → (1) | → (1) | → (1) | → (1) | → (1) | → (1) | → (1) | → 384−432 (6) | → (6) |
| 416−417 (1) | → (1) | → 413−417 (2) | → (2) | → (2) | → (2) | → (2) | → (2) | | |
| | | | | | | | | 528−563 (3) | → 509−608 (7) |
| | | | | | | | | 583−608 (2) | |
| 666−667 (1) | → (1) | → (1) | → (1) | → (1) | → (1) | → (1) | → (1) | → 666−684 (4) | → (4) |
| 683−684 (1) | → 681− 684 (2) | → (2) | → (2) | → (2) | → (2) | → (2) | → (2) | | |
| 742−743 (1) | → (1) | → (1) | → (1) | → (1) | → (1) | → (1) | → 733−757 (5) | → (5) | → 733−777 (6) |
| 752−753 (1) | → (1) | → (1) | → 752−757 (2) | → (2) | → (2) | → (2) | | | |
| | | | | | | | | 803−814 (1) | → 803−833 (2) |

## Example Y 8

Short gears are poorly occupied; therefore, the catch is too scarce to get both the observed-values and the estimated ones in both the interval analysis and the ar-

rangement one high enough to be free from severe influence of accidental error; consequently it is difficult to deduce any structure of significance. Accordingly, I do not wish to give any further interpretation than those briefly described in the below.

1) The first peak of the observed-values in the interval analysis is assumed to be at one hook-interval. Therefore, set this width as the key-length to the elemental step, and the strong schooling-tendency is suggested from the fact that as many as eight clusters are observed apparently, against the fact that no more than $2\frac{1}{2}$ clusters are expected to be observable from the chance distribution.

2) The schooling tendency is also suggested from such results at respective steps of analyses as the high observed-values of the lots of large population-size and *vice versa*.

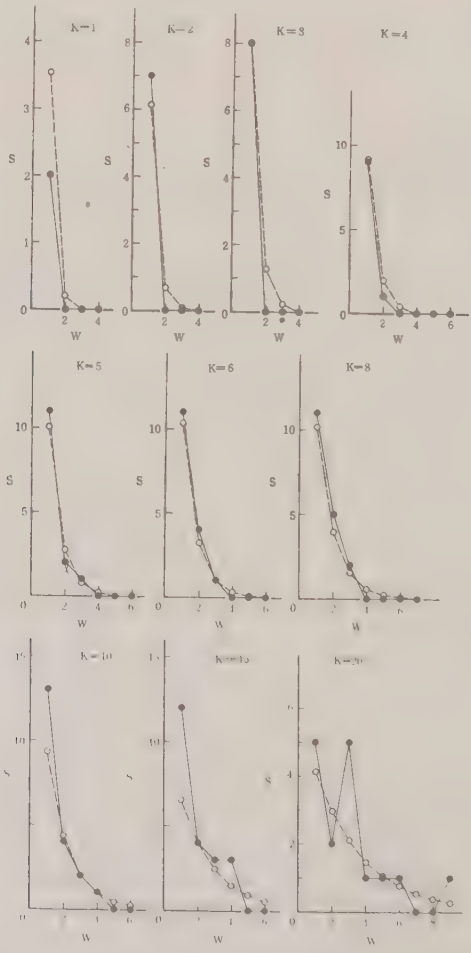



Fig. 58. The deviation of the numbers of the apparent clusters of respective population sizes, in contrast with that of the theoretically estimated numbers of the false clusters, when respective $k$ are set to be the key-lengths to decoding the distribution patterns (Example Y 9 ).

Table 19. The positions of the apparent clusters and the changes in their features with increase in $k$ (Example Y 9).

| 1 | 2 | 3 | 4 | 5 | 6 | 8 | 10 | 15 | 20 |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 89−97 (1) | → (1) | → (1) | → (1) |
| | | | 147−151 (1) | → (1) | → (1) | → (1) | → (1) | → (1) | → (1) |
| | | | | | | | | 189−203 (1) | → (1) |
| | 276−278 (1) | → (1) | → (1) | → 271−283 (3) | → (3) | → (3) | → 261−283 (4) | → (4) | 261−317 (6) |
| | | | | | | | | 302−317 (1) | |
| | | 339−342 (1) | → (1) | → (1) | → (1) | → (1) | → (1) | → 339−354 (2) | → 339−372 (3) |
| | 414−416 (1) | → (1) | → (1) | → (1) | → 408−416 (2) | → 408−424 (3) | → (3) | → (3) | → (3) |
| | 469−471 (1) | → (1) | → (1) | → (1) | → (1) | → 461−471 (2) | → (2) | → 446−471 (3) | → (3) |
| | | | | | | | 496−506 (1) | → (1) | |
| | | | | 522−527 (1) | → (1) | → (1) | → (1) | → 522−546 (4) | → 496−583 (9) |
| | 544−546 (1) | → (1) | → (1) | → (1) | → 538−546 (2) | → (2) | → (2) | | |
| | | | | 578−583 (1) | → (1) | → (1) | → (1) | → 563−583 (2) | |
| 641−642 (1) | → (1) | → (1) | → (1) | → (1) | → (1) | → (1) | → (1) | → (1) | → 641−682 (4) |
| | | | | | 658−664 (1) | → 658−682 (2) | → (2) | → (2) | |
| | | | | 708−713 (1) | → (1) | → (1) | → (1) | → (1) | → (1) |
| | | | | | | | 743−752 (1) | → (1) | → 743−781 (3) |
| | | | | | | | | 769−781 (1) | |
| | | | | 841−846 (1) | → (1) | → (1) | → (1) | → (1) | → 841−863 (2) |
| | | | | | 887−893 (1) | → (1) | → (1) | → 887−916 (3) | → (3) |
| | | | | | | 908−916 (1) | → (1) | | |
| 963−964 (1) | → (1) | → (1) | → (1) | → 958−964 (2) | → (2) | → (2) | → (2) | → (2) | → (2) |
| | 1007−1009 (1) | → (1) | → 1007−1013 (2) | → (2) | → (2) | → (2) | → 1007−1023 (3) | → 1007−1038 (4) | → 991−1062 (7) |
| | | | 1058−1062 (1) | → (1) | → (1) | → (1) | → (1) | → (1) | |
| | | | | | | | | 1131−1143 (1) | → (1) |

## Example Y 9

No further fact than those described in the below can be deduced, because of the low observed-values and the estimated ones due to poor total-catch.

1) When a length shorter than five hook-intervals is set to be the key-length, the apparently observed number of the clusters of any population-size can not reach the theoretical one; this suggests that individuals seem to be hooked rather self-spacingly.

2) Moreover, when the key-length is neither shorter than five hook-intervals nor longer than 10, none of the apparently observed clusters are constituted of more than five or six hooked-individuals, while the deviation of the observed-values shows that the clusters of small population-size are more frequently observable than expected from the chance distribution. And these facts also seem to support the self-spacing pattern.

3) And even when the key-length is elongated into as long as 15 hook-intervals, none of the deviation are incapable of being negligible, except the higher observed-value at $W=1$; this means that the clusters being able to be regarded as the true

ones are only five ones constituted of each two hooked-individuals.

4) Furthermore, if the key-length is increased to the width as long as 20 hook-intervals, the estimated numbers of the lots still keep a sharp decrease with increase in their population-size. And even if to say committing against the presupposable severe-influence of accidental error, we can not find out any true-cluster other than no or one cluster constituted of two hooked-individuals, three or one less clusters of each four hooked-individuals and perhaps including a cluster constituted of 10 hooked-individuals and covering the part from the first hook in the 100th basket (H. N. 496) to the third hook in the 117th basket (H. N. 583).

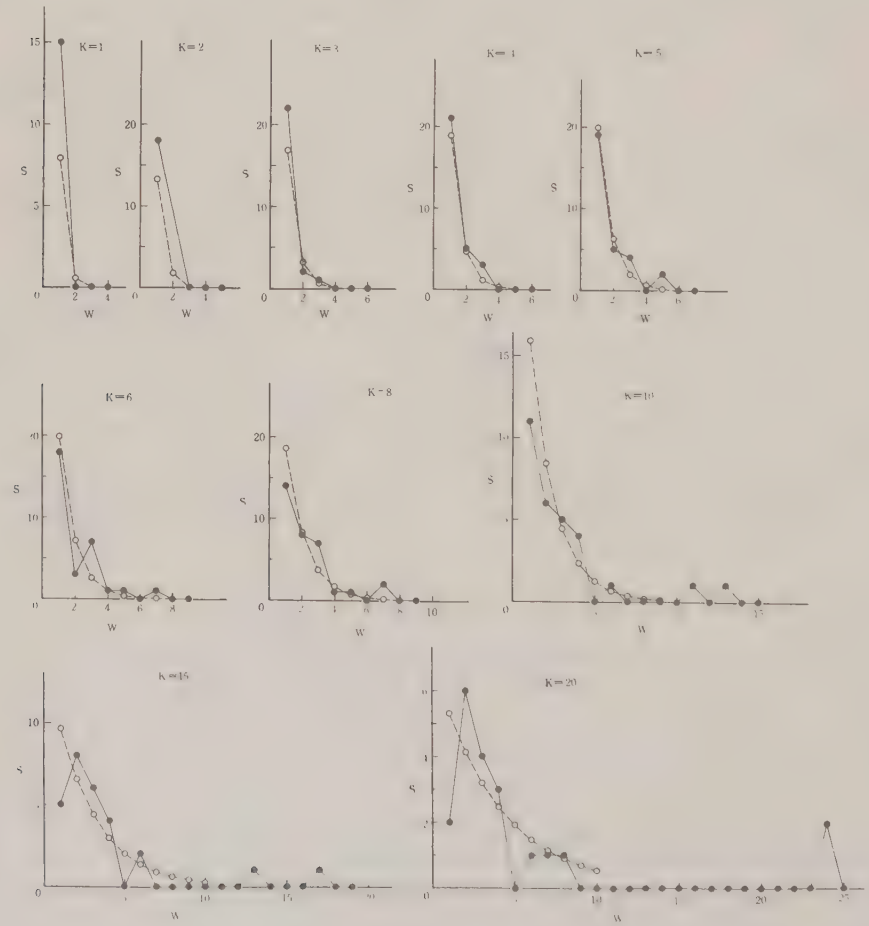
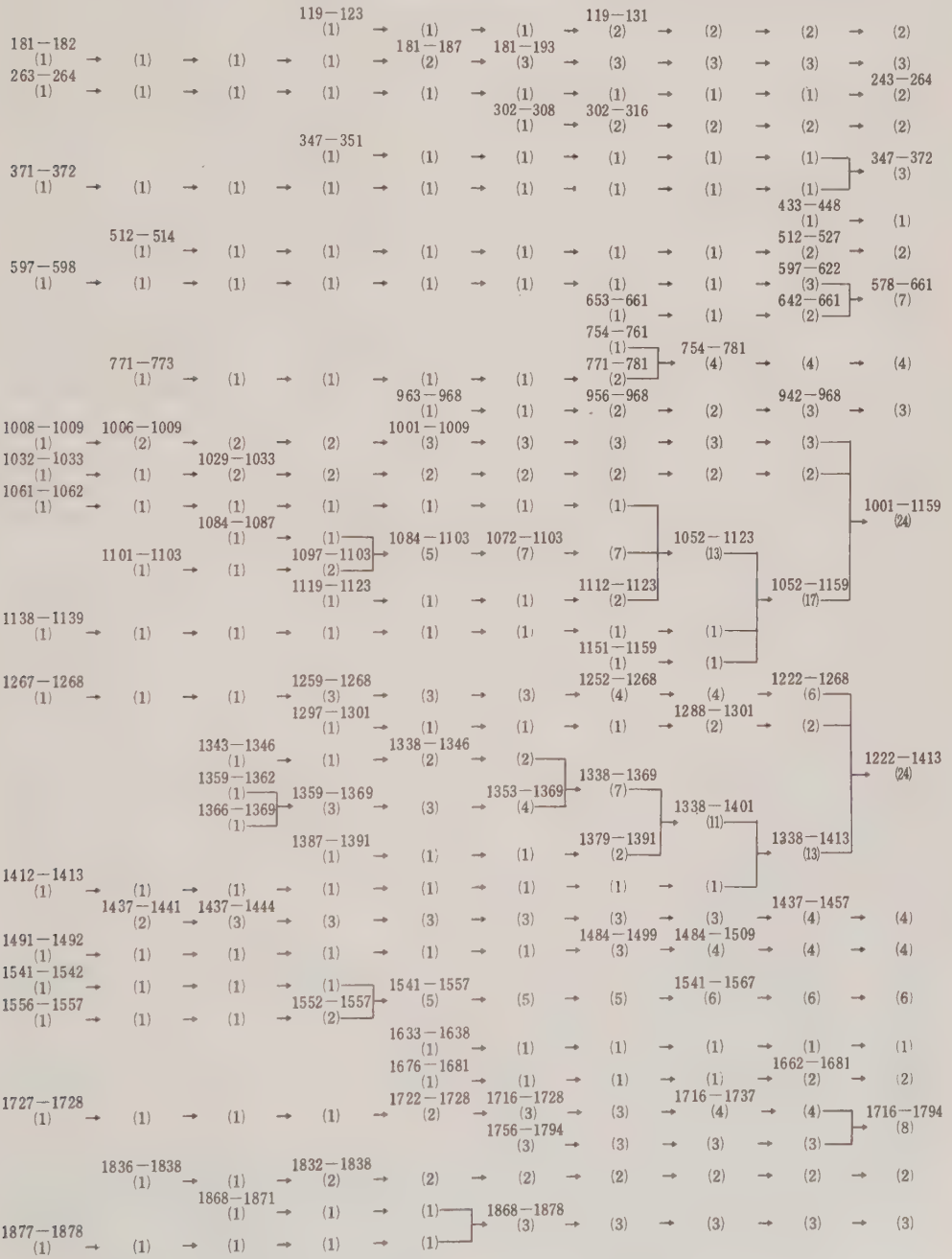



Fig. 59. The deviation of the numbers of the apparent clusters of respective population sizes, in contrast with that of the theoretically estimated numbers of the false clusters, when respective $k$ are set to be the key-lengths to decoding the distribution patterns (Example Y 10).

Table 20. The positions of the apparent clusters and the changes in their features with increase in $k$ (Example Y 10).



Example Y 10

It is one of the characteristics of the distribution pattern of this example that, when we neglect slight deviations of the observed-values in the interval analysis at $k = 2$ and 3, the observed-values within eight hook-intervals are continuously higher than the estimated ones; this seems to mean that the intervals forming the elemental-clusters in this example are far longer than those of the other examples, in other words, the contagiousness at the elemental step reaches the wider range than those of the other examples and is as long as eight hook-intervals. And when we consider this fact together with a little lower occupied-rate, it is suggested that the population seems to be more dispersing than in the other examples, but it still keeps a contagious pattern. Keeping the above-mentioned facts in mind, let us analyze the distribution pattern of this example; then the following results will be obtained.

*Structure at the elemental step* ($k = 1$ *or* 8) : As mentioned above, the key-length to this step is thought to be eight hook-intervals; but when we regard the slight deviations of the observed-values in the interval analysis at 2 and 3 hook-intervals as significant, one hook-interval can be regarded as the key-length; then the distribution pattern is decoded as follows: the population seems to contain seven true-clusters constituted of each two individuals hooked adjoiningly, which occupy about 1/10 of total catch. But when the deviations at 2 and 3 hook-intervals are regarded to be insignificant, the key-length becomes as long as eight hook-intervals and the following pattern is deducible. Because of the schooling tendency, the single isolated-intervals are not so frequently observable as expected from the chance distribution; while three more clusters constituted of each four hooked-individuals and two more clusters of each eight hooked-individuals than expected from the chance distribution are observable, complementing the insufficiency of the number of the single intervals observed actually; and these clusters are thought to be the true ones at the elemental step. And the hooked positions of the clusters of small population-size are uncertain because of the difficulties of distinguishing the true ones constituted of each three hooked-individuals from the false ones of the same population-size observable even as the results of the chance distribution. And a little less than 20 % of total catch is thought to be derived from these true-clusters. Here, for reference' sake, I must describe the fact that the elemental-clusters of such a large population-size as eight individuals seem to be as if to indicate where the occupied-rate of the hooks located there is extremely high, but actually, the average occupied-rate of the hooks is not so high, and is only about a little higher than one individual per basket, because of long key-length in company with the low occupied-rate.

*Structure at the second order* ($k = 20$) : All the observed-values and the estimated ones in the interval analysis in the range $k > 10$ do not reach five. Accordingly, whether the obscurely high observed-values at $k = 10$, 13 and 15 can be regarded as significant or not is doubtful, because the interval analysis may be severely suffered from the influence of accidental error; but it has little less risk to be suffered from the influence of accidental error to consider that the observed-value in the interval analysis at 20 hook-intervals may, perhaps, be significantly higher than the esti-

mated one and is regarded as the key-length to the second order. Accordingly, when we set 20 hook-intervals as the key-length, the distribution pattern of the probable second order, which may be the highest order observable within a row, is decoded as follows: the deviation of the observed-values from the estimated ones seems to allude to the presence of some true-clusters of small population-size; but it seems to be better to regard that there is no true-cluster of small population-size, because the low observed-values and the estimated ones have much risk to introduce severe influence of accidental error into the decoding of the pattern, which makes it impossible to give any significance to the above-mentioned deviation. On the other hand, two clusters of large population-size pointed out at the preceding step of analysis are swelled their population-size into each 25 hooked-individuals, and they are raised to be regarded as the true-clusters at this step. And they seem to be situated side by side at the parts respectively from the first hook in the 201th basket (H. N. 1001) to the last hook in the 232th basket (H. N. 1159) and from the second hook in the 245th basket (H. N. 1222) to the third hook in the 283th basket (H. N. 1413). Thus, the population seems to contain two schools, each of which is constituted of 1/5 of total catch and covering 9 and 11 % of a whole length of a row. But examining on Table 20, we may be aware of the fact as one of the characteristics of the distribution pattern of these schools, especially of the latter one, that, in contrast with the fact that the intervals of one hook-interval width or thereabout are the principal ingredient of the schools of the similar population-size in the other examples, the schools in this example do not contain so many intervals of such a narrow width as one hook-interval; this fact seems also to reflect the dispersed pattern pointed out at the top of the description of this example.

**Example Y 11**

Good catch by long gears raises the observed-values in the interval analysis enough to estimate the key-lengths being suffered from scarcely any influence of accidental error. Notwithstanding, the gradient, the exclusion of the influence of which on the interval analysis is too troublesome, is expected to be strongly influential, which makes it difficult to find out the key-lengths. But, it may be said that the observed-values in the interval analysis within three hook-intervals are continuously higher than the theoretical ones, even if the influence of the gradient is taken into consideration. And the high observed-values in the interval analysis in the range from $k = 17$ to 19 may also be significant. Moreover, when we refer to the deviations, some significance may be given to the high observed-value in the interval analysis at $k = 10$, although it does not exceed the theoretical one. Accordingly, regarding these three lengths as the key-lengths to decoding of the distribution pattern, let us analyze the pattern of this example.

*Structure at the elemental step* ($k = 3$) : The lots of small population-size are not so frequently observable as expected from the chance distribution; complementing them, the lots of large population-size are far more frequently observable than expected, because chiefly of strong cluster-formation at the elemental step and partly of the

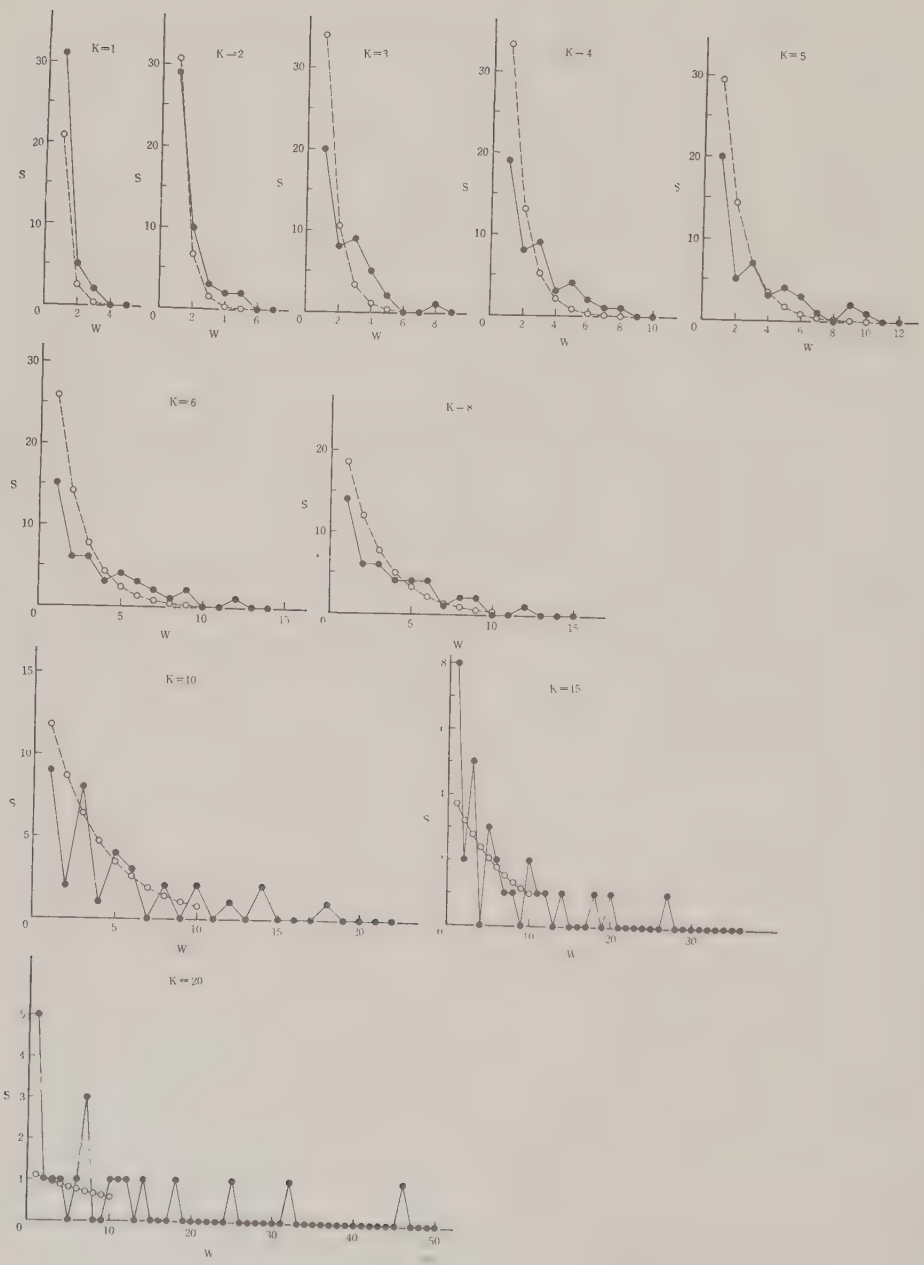
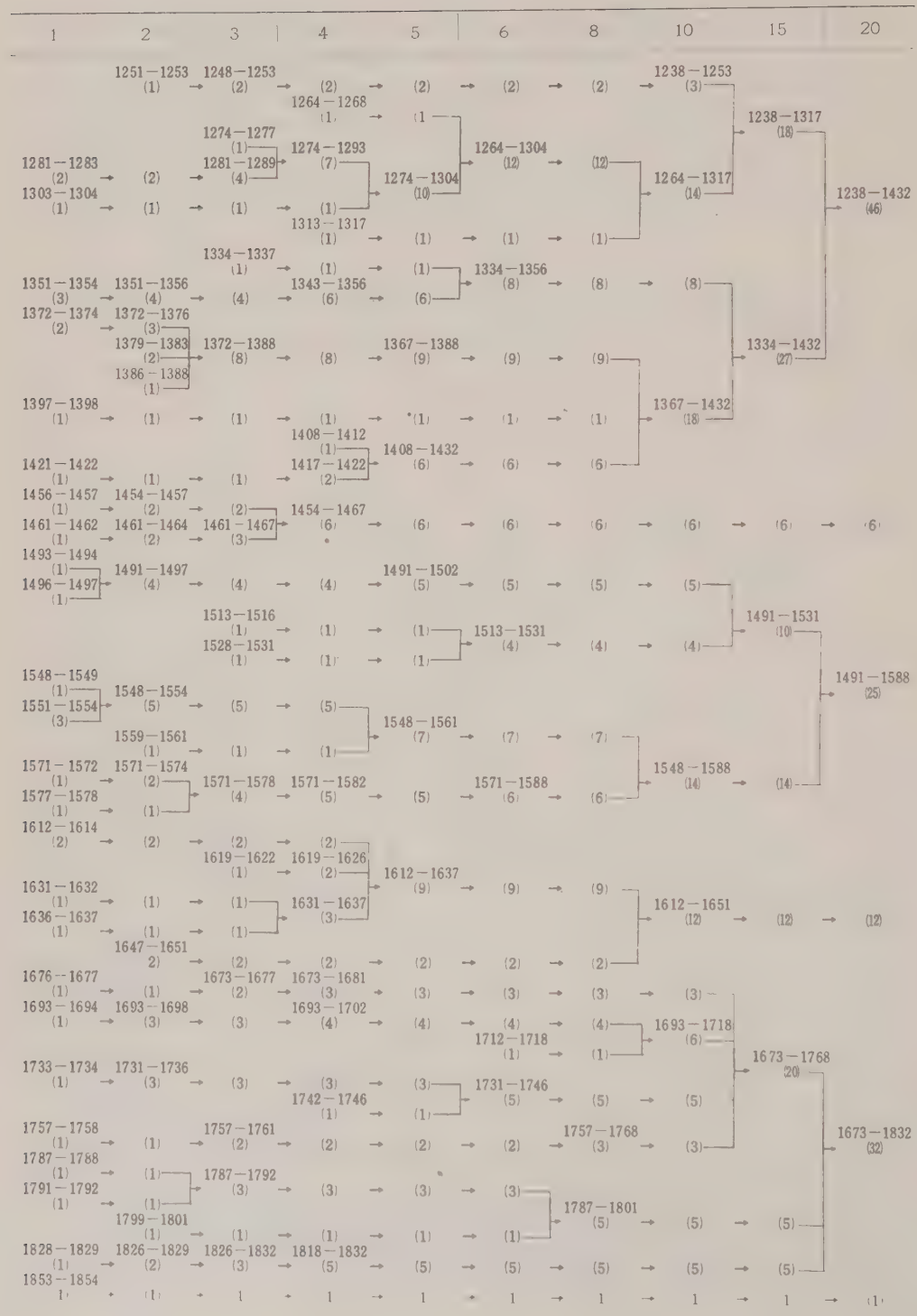



Fig. 60. The deviation of the numbers of the apparent clusters of respective population sizes, in contrast with that of the theoretically estimated numbers of the false clusters, when respective $k$ are set to be the key-lengths to decoding the distribution patterns (Example Y11).

high observed-values in the interval analysis at one hook-interval and of the high occupied-rate. And the above-mentioned facts cause the gradual decrease in the observed numbers of the lots with increase in their population-size. That is to say, the apparently observed numbers of the clusters constituted of each as many as or less than three hooked-individuals can not reach the numbers expected from the chance distribution, but six more clusters constituted of each four hooked-individuals, four more ones of each five hooked-individuals and one and two more clusters of six and three more hooked-individuals than those expected from the chance distribution are

Table 21. The positions of the apparent clusters and the changes in their features with increase in $k$ (Example Y 11).

| 1 | 2 | 3 | 4 | 5 | 6 | 8 | 10 | 15 | 20 |
|---|---|---|---|---|---|---|---|---|---|
| 8−9 (1)<br>12−13 (1) | (1)<br>(1) | 8−13 (3) | (3) | (3) | (3) | (3) | (3) | (3) | (3) |
| | | | | | | | | | 61−79 (1) |
| | | | 117−121 (1) | (1) | (1) | (1) | 107−121 (2) | (2) | 107−162 (7) |
| 142−143 (1) | (1) | 139−146 (3) | (3) | (3) | (3) | (3) | (3) | (3) | |
| | 207−211 (2) | 204−211 (3) | (3) | (3) | (3) | (3) | (3) | 193−236 (7) | (7) |
| | 234−236 (1) | (1) | (1) | (1) | (1) | (1) | (1) | | |
| | | | | | 391−397 (1) | (1) | (1) | (1) | (1) |
| | | | | 448−453 (1) | (1) | (1) | (1) | (1) | 411−471 (4) |
| | | | | | | | | 501−513 (1) | (1) |
| | | | | | | 557−572 (2) | 547−572 (3) | 534−587 (5) | 534−607 (7) |
| 606−607 (1) | (1) | (1) | (1) | (1) | (1) | (1) | (1) | (1) | |
| | | | | 654−659 (1) | (1) | (1) | (1) | (1) | (1) |
| | | | | | | | | 687−702 (1) | 687−722 (2) |
| 762−764 (2) | (2) | 762−767 (3) | (3) | 762−772 (4) | (4) | (4) | 743−772 (6) | (6) | |
| | 789−791 (1) | (1) | (1) | (1) | (1) | (1) | (1) | (1) | 743−861 (18) |
| 826−827 (1)<br>831−833 (2) | 826−833 (5) | (5) | (5) | (5) | (5) | 826−841 (6) | 826−861 (8) | (8) | |
| | | | | | 936−942 1) | (1) | (1) | 911−942 (3) | |
| | 964−966 (1) | 961−966 (2) | (2) | (2) | (2) | (2) | (2) | 961−979 (3) | 911−1017 (10) |
| | | | | | | 997−1004 (1) | (1) | 997−1017 (2) | |
| | | | 1059−1063 (1) | (1) | 1059−1069 (2) | (2) | | | |
| | 1082−1084 (1) | 1079−1084 (2) | (2) | (2) | (2) | (2) | 1059−1116 (10) | 1044−1116 (11) | (11) |
| 1101−1102 (1) | (1) | (1) | (1) | (1) | (1) | 1093−1116 (4) | | | |
| 1142−1143 (1)<br>1147−1148 (1) | (1)<br>(1) | (1) | 1142−1148 (3) | (3) | (3) | (3) | (3) | (3) | 1142−1206 (14) |
| | | | 1164−1168 (1) | (1) | (1) | (1) | 1164−1206 (10) | (10) | |
| 1177−1178 (1)<br>1187−1188 (1)<br>1191−1192 (1) | (1)<br>(1) | (1)<br>1184−1192 (4) | (1)<br>(4) | (1)<br>(4) | 1177−1198 (7) | 1177−1206 (8) | | | |


1 2 3 4 5 6 8 10 15 20
1251−1253 (1) → 1248−1253 (2) → (2) → (2) → (2) → (2) → 1238−1253 (3)
1264−1268 (1) → (1)
1238−1317 (18)
1274−1277 (1)
1281−1283 (2) → (2) → 1281−1289 (4) → 1274−1293 (7)
1264−1304 (12) → (12)
1303−1304 (1) → (1) → (1) → (1) → 1274−1304 (10)
1264−1317 (14)
1238−1432 (46)
1313−1317 (1) → (1) → (1) → (1)
1334−1337 (1) → (1) → (1)
1351−1354 (3) → 1351−1356 (4) → 1343−1356 (6) → (6)
1334−1356 (8) → (8) → (8)
1372−1374 (2) → 1372−1376 (3)
1379−1383 (2) → 1372−1388 (8) → (8) → 1367−1388 (9) → (9) → (9)
1386−1388 (1)
1334−1432 (27)
1397−1398 (1) → (1) → (1) → (1) → (1) → (1) → (1)
1367−1432 (18)
1408−1412 (1)
1421−1422 (1) → (1) → (1) → 1417−1422 (2) → 1408−1432 (6) → (6) → (6)
1456−1457 (1) → 1454−1457 (2) → (2)
1461−1462 (1) → 1461−1464 (2) → 1461−1467 (3) → 1454−1467 (6) → (6) → (6) → (6) → (6) → (6) → (6)
1493−1494 (1)
1496−1497 (1) → 1491−1497 (4) → (4) → (4) → 1491−1502 (5) → (5) → (5) → (5)
1491−1531 (10)
1513−1516 (1) → (1) → (1)
1528−1531 (1) → (1) → (1)
1513−1531 (4) → (4) → (4)
1548−1549 (1)
1551−1554 (3) → 1548−1554 (5) → (5) → (5)
1491−1588 (25)
1559−1561 (1) → (1) → (1)
1548−1561 (7) → (7) → (7)
1571−1572 (1) → 1571−1574 (2)
1577−1578 (1) → (1)
1571−1578 (4) → 1571−1582 (5) → (5) → 1571−1588 (6) → (6)
1548−1588 (14) → (14)
1612−1614 (2) → (2) → (2) → (2)
1619−1622 (1) → 1619−1626 (2)
1612−1637 (9) → (9) → (9)
1631−1632 (1) → (1) → (1)
1636−1637 (1) → (1) → 1631−1637 (3)
1612−1651 (12) → (12) → (12)
1647−1651 2) → (2) → (2) → (2) → (2) → (2)
1676−1677 (1) → (1) → 1673−1677 (2) → 1673−1681 (3) → (3) → (3) → (3) → (3)
1693−1694 (1) → 1693−1698 (3) → (3) → 1693−1702 (4) → (4) → (4) → (4)
1693−1718 (6)
1712−1718 (1) → (1)
1673−1768 (20)
1733−1734 (1) → 1731−1736 (3) → (3) → (3)
1731−1746 (5) → (5) → (5)
1742−1746 (1) → (1)
1757−1758 (1) → (1) → 1757−1761 (2) → (2) → (2) → (2) → 1757−1768 (3) → (3)
1673−1832 (32)
1787−1788 (1) → (1)
1791−1792 (1) → 1787−1792 (3) → (3) → (3) → (3)
1787−1801 (5) → (5) → (5)
1799−1801 (1) → (1) → (1) → (1) → (1)
1828−1829 (1) → 1826−1829 (2) → 1826−1832 (3) → 1818−1832 (5) → (5) → (5) → (5) → (5) → (5)
1853−1854 (1) → (1) → 1 → 1 → 1 → 1 → 1 → 1 → (1)

observable and they are thought as if to be regarded as the true-clusters due to schooling tendency. But it is probable that some of them may be not the true ones but the false ones indebted to the gradient, because the gradient expects to cause some false-clusters occurred more frequently with approach to the final end of hauling of a row. Accordingly, it may well be thought that catch from less than 13 clusters at the elemental step occupies 1/4 of total catch; while catch from single-individuals, which are swimming solitarily or falsely forming clusters due to even the chance distribution or due to the gradient, reaches three times as many as that from the former.

*Structure at the second order* ($k = 10$) : The high observed-values in Fig. 60-(10) at $W = 3$ and 10 seem to allude to the presence of some clusters; but when the influence of accidental error due to the low observed-values is taken into consideration, the significance of the presence of them becomes highly doubtful. But, even if the influence of the gradient is taken into consideration, there may be no doubt about the presence of a cluster constituted of 19 hooked-individuals and covering the range from the second hook in the 274th basket (H.N. 1367) to the hook of the same order spaced by 13 baskets (H.N. 1432). And also it is suspected, even if the influence of the gradient is taken into consideration, that among a cluster constituted of 13 hooked-individuals and two clusters of 15 hooked-individuals, at least one or two may well be regarded as the true ones due to the schooling tendency.

*Structure at the highest order* ($k = 20$) : The theoretical number of the intervals longer than 20 hook-intervals is estimated to be as many as 16 among 229 total ones; this fact results in the small number of the lots actually observed and estimated, moreover the high occupied-rate also causes a very slight decrease in the number of the lots with increase in their population-size. Accordingly, the estimated numbers of the lots of respective population-size are expected to be far lower; and this fact makes it hardly possible to guess the pattern free from the influence of accidental error. And even if dare to say committing against severe influence of accidental error and of the gradient, I can not deduce any fact but mentioned below. Four clusters constituted of each two hooked-individuals among five apparently observed ones and two of each eight hooked-individuals among three apparent ones are probably regarded as the true-schools of small population-size. But among the apparently observed clusters of respective population-size, those having the more intervals of narrow width are the more probable to be the true ones. And also, among four clusters constituted of from 11 to 15 hooked-individuals, at least two are well regarded as the true ones. Moreover, it is more probable that all or at least one less of four clusters of such a large population-size as 19, 26, 33 and 46 hooked-individuals respectively are regarded as the true ones due to the schooling tendency; and their hooked positions, widths, average occupied-rates, *etc.* are estimative from Table 21. Accordingly, at least about as many as a half of catch is thought to be derived from as many as or more than 11 schools of not so strong contagiousness.

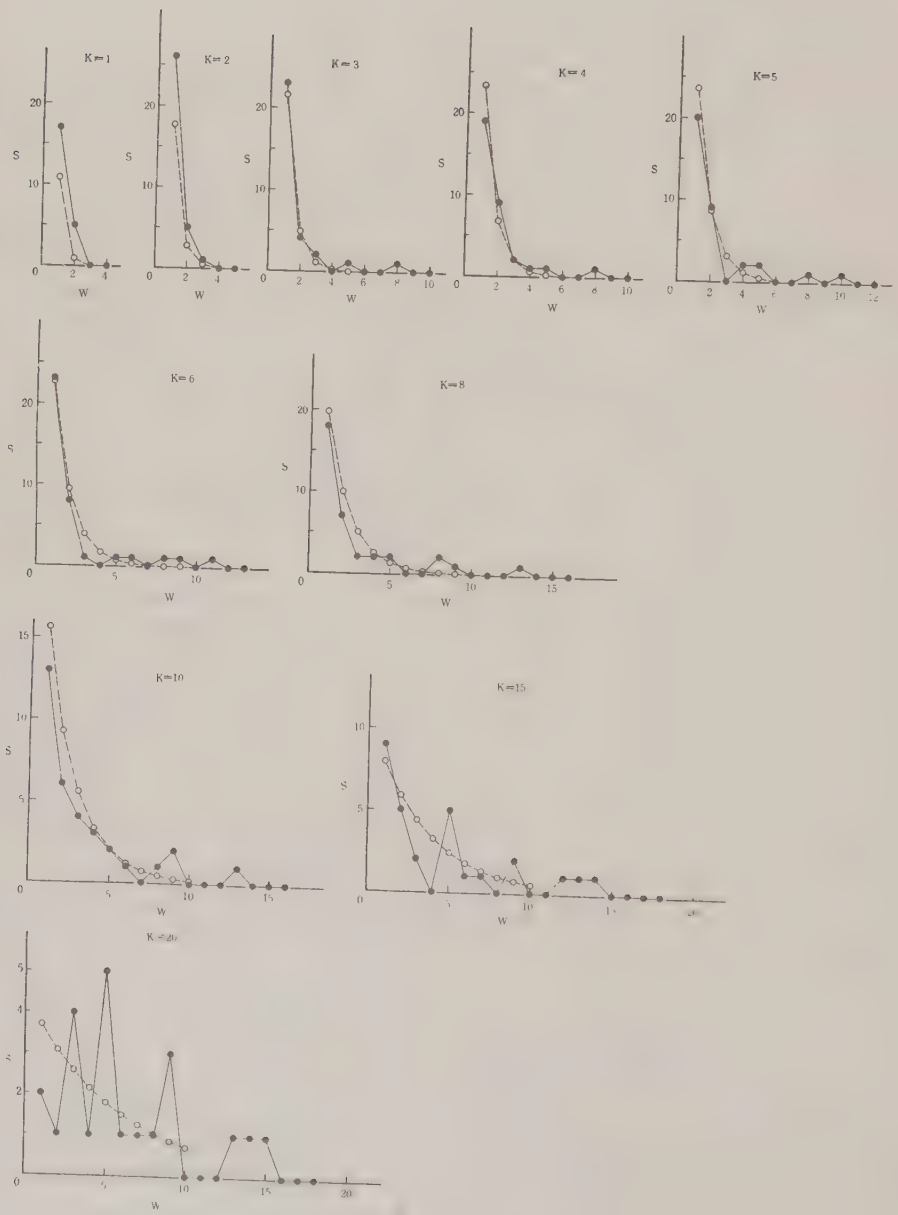
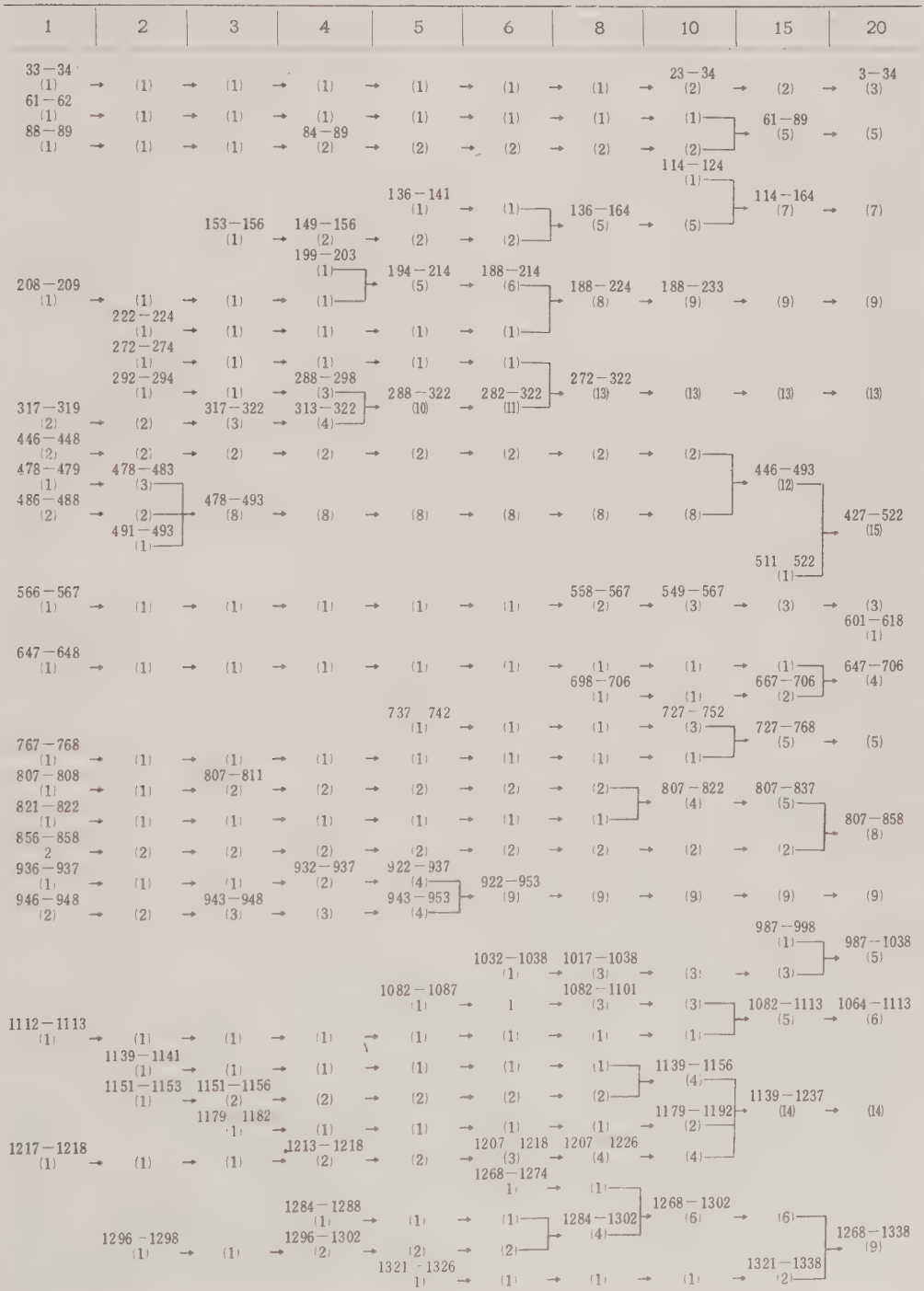
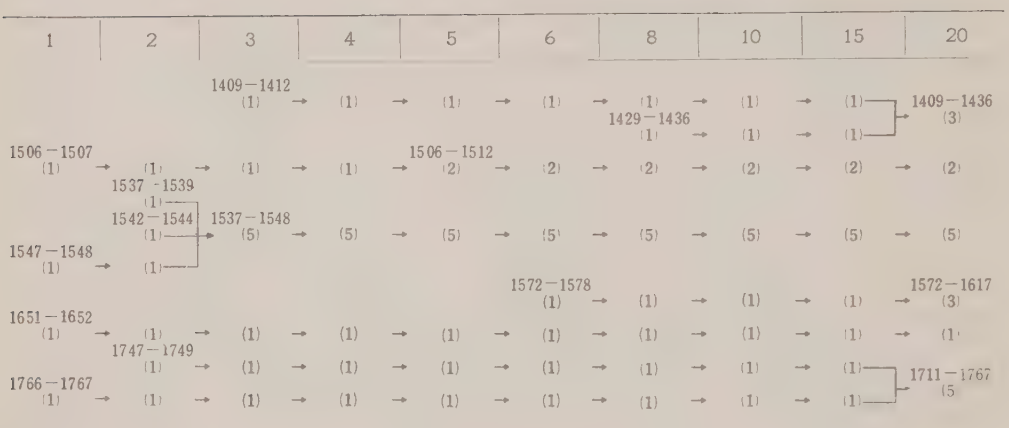



Fig. 61. The deviation of the numbers of the apparent clusters of respective population sizes, in contrast with that of the theoretically estimated numbers of the false clusters, when respective $k$ are set to be the key-lengths to decoding the distribution patterns (Example Y12).

Table 22. The positions of the apparent clusters and the changes in their features with increase in $k$ (Example Y 12).






**Example Y 12**

Most of the observed-values and the estimated ones in the interval analysis in the range $k > 10$ do not reach five, which has much risk to introduce severe influence of accidental error into the decoding; but it may well be acceptable to regard that 3, 5, 8, 11, 15 and 20 hook-intervals are the key-lengths to decoding of the distribution pattern. And when we regard them as key-lengths, the following results are obtained as the distribution pattern at respective steps.

*Structure at the elemental step* ($k = 3$) : It is rather clearly suggested from Fig. 61 - (3) that two clusters constituted of six and three more hooked-individuals are surely the true-clusters at the elemental step due to the schooling tendency; and they are thought to be hooked in the ranges respectively from the second hook in the 308th basket (H. N. 1537) to the third hook in the 310th basket (H. N. 1548) and from the third hook in the 96th basket (H. N. 478) to the hook of the same order spaced by three baskets (H. N. 493). Besides them, the presence of the other elemental-clusters constituted of two or four hooked-individuals is also suggested.

*Structure at the second order* ($k = 5$) : The presence of two clusters constituted of six and five more hooked-individuals is suggested from Fig. 61 - (5); and they are guessed to be hooked in the beginning $\frac{1}{6}$ of hauling of a row —— from the last hook in the 39th basket (H. N. 194) to the hook of the same order spaced by four baskets (H. N. 214) and from the third hook in the 58th basket (H. N. 288) to the second hook in the 65th basket (H. N. 322), respectively; and also two elemental-clusters of large population-size are suffered from no change in their features, and are also regarded as the true-clusters at this step. And the high observed number of the lots constituted of five hooked-individuals seems to suspect that some of the clusters of such a population-size as this are the true ones, but whether we can give any significance to this suspection or not is somewhat doubtful.

*Structure at the third order* ($k = 8$) : All the clusters regarded as the true ones at the preceding step of analysis, except that hooked at the latter-most part which is also regarded as an elemental-cluster, are swelled their population-size and keep the

features of the true-clusters at this step. Besides them, the occurrence in another cluster is suspected; this is a boundle of a pair of the clusters arranged successively and constituted of each five hooked-individuals, although the results at the preceding step of analysis still have a doubt about the significance of regarding each of them as the true one. Accordingly, about 1/4 of total catch distributed within 7 % of whole length of a row is thought to form four clusters at this step. And, it seems to be one of the characteristics of the structures of the true-clusters at this step in this example that all of the true-clusters are narrow but densely crowded and hooked in the beginning half of a row especially in the beginning 1/4 or thereabout.

*Structure at the fourth order* ($k = 11$) : For convenience' sake of comparison with other examples, the figure showing the result at $k = 10$ is represented, against the fact that the key-length to this step is estimated to be 11 hook-intervals. But there are eight intervals of 11 hook-intervals wide and among them, two are observable as solitarily, one forms a lot of two intervals, while the rest five form four lots of five intervals. Accordingly, if we wish to get the figure showing the result of the arrangement analysis at $k = 11$, the observed-values in Fig. 61-(10) should be corrected for the above-mentioned influence of the intervals of 11 hook-intervals wide and the theoretical-values at smaller $W$ must be decreased slightly while those at larger $W$ must be increased slightly. Then, the following clusters are guessed to be the true ones.

1) Three clusters among four of those recognized as the true-ones at the preceding step: they are suffered from no change and keep the same features as those at the preceding step; they are thought to cover the parts respectively from the third hook in the 96th basket (H. N. 478) to the hook of the same order spaced by three baskets (H. N. 493) (constituted of nine hooked-individuals), from the second hook in the 185th basket (H. N. 922) to the third hook in the 191th basket (H. N. 953) (10 hooked-individuals) and from the second hook in the 55th basket (H. N. 272) to the hook of the same order spaced by 10 baskets (H. N. 322) (14 hooked-individuals).

2) The other cluster regarded to be also the true one at the preceding step: it swells its population-size by fusion with a single individual and covers the part from the third hook in the 38th basket (H. N. 188) to the hook of the same order spaced by nine baskets (H. N. 233) (constituted of 10 hooked-individuals).

3) Four clusters or thereabout among six apparent ones constituted of each hooked-individuals: they are any four of those covering the parts respectively six from the first hook in the 13th basket (H. N. 61) to the last hook in the 17th basket (H. N. 89), from the first hook in the 28th basket (H. N. 136) to the last hook in the 33th basket (H. N. 164), from the second hook in the 217th basket (H. N. 1082) to the third hook in the 223th basket (H. N. 1113), from the last hook in the 228th basket (H. N. 1139) to the second hook in the 234th basket (H. N. 1167), from the second hook in the 242th basket (H. N. 1207) to the hook of the same order spaced by six baskets (H. N. 1237) and from the second hook in the 308th basket (H. N. 1537) to the third hook in the 310th basket (H. N. 1548).

Therefore, when we set the true-clusters constituted of six hooked-individuals are the narrower four, about a half of total catch distributed within 12% of a whole length of a row seems to form eight clusters. And it seems to be one of the characteristics of the distribution pattern of these clusters that the narrow but rather densely crowded clusters are somewhat evenly distributed throughout a row.

*Structure at the fifth order* ($k = 15$): The fifth peak of the observed-values in the interval analysis can be found at $k = 15$. But the intervals neither shorter than 11 hook-intervals nor longer than 15 hook-intervals are only as many as eight; therefore, essentially not so different pattern from that at the preceding step is expected to be observable, except the fact that some true-clusters at the preceding step swell their population-size. And no further description is given, because the pattern is easily deducible from Table 22 considering together with the pattern at the preceding step.

*Structure at the highest order* ($k=20$): It is very hard to deduce the pattern at this step with scarcely any influence of accidental error, because of the low observed-values and the estimated ones. And even if dare to say committing against severe influence of accidental error, any fact but the below-mentioned one is deducible: seven or one less clusters —— which are two or one more clusters among five apparently observed ones constituted of each six hooked-individuals, two or one less cluster among three constituted of each 10 hooked-individuals —— are able to be regarded as the true ones due to the schooling tendency.

## 2. Summarized results of the arrangement analysis

Summarizing the descriptions in the paragraph "exposition of particular example", the following facts can be admitted to describe as the general structure of the distribution pattern of the yellow-fin tuna projected along long-lines observed in this series of operations analyzed through the arrangement method:

1) Population usually has the structures of several-fold contagiousness.

2) The usual structure at the highest order observable within a whole length of a row is thought as follows: about a half of total catch constitutes several schools and the average occupied-rate of the hooks in the parts covered by them is from several tenths to several times higher than that estimated from throughout a row.

3) But there are examples showing some special structures. For instances, even if the key-length is not so long, the schooling tendency in the usual examples makes it possible to be observed some true clusters at the elemental step or at lower orders constituted of a little many hooked-individuals, moreover to be observed some schools of large population-size covering wide range, when the key-length is long; but it is suggested as one of the characteristics of the distribution pattern of the yellow-fin tuna in Example Y 4 that there is no elemental-cluster or cluster at lower orders constituted of a little large population-size moreover the clusters of small population-size are rather evenly or at least randomly distributed throughout a whole length of a row, consequently the population does not contain any school of large population-size

covering a wide range; the clusters at respective orders constituted of rather many hooked-individuals are frequently observable in the population of the yellow-fin tuna in Example Y 7; aggregations at respective steps in the population of the yellow-fin tuna in Example Y 10 are rather scattered ones in which no individual is hooked so closely one another, while rather narrowly but densely crowded clusters of relatively large population-size are observable in the population of the yellow-fin tuna in Example Y 12.

## 3. Comparison of the results of the arrangement analysis with those of the spacing one

The results of this arrangement analysis are rather compared to corresponding to those of the spacing one, in which various unit-lengths including one hook-interval width are adopted, against the fact that the results of the interval analysis are compared to corresponding to those of the spacing one in which one hook-interval width is adopted as the unit-length under consideration. On the other hand, the results of the arrangement analysis can tell us the number of the aggregations of respective population-size as easily noticed from the descriptions in the first paragraph of this part, in contrast with the fact that the results of the spacing analysis simply tell us the probable distances among the centers of the schools —— secondarily the total number of the schools regardless of their population-size is estimative. Moreover, it is far easier to translate the facts guessed out from the results of the arrangement analysis into the projected distribution pattern recorded actually than to translate those of the spacing analysis into it; and also when we refer to the results of the arrangement analysis together with the projected distribution pattern recorded actually, far more detailed facts than those from the results of the spacing one are deducible —— for examples, the numbers of the schools of respective population-size, their probable positions, widths, consequently occupied-rates, *etc.*, of course including the distances among their centers.

In addition to these merits, it is one of the most powerful merits of adopting the arrangement analysis that the individuals forming respective aggregations pointed out from the results of the arrangement analysis have theoretically a definite proof supporting that these individuals are hooked aggregatively, in contrast with the fact that the observed-value at a certain $k$ in the spacing analysis exceeds largely the theoretical one simply means, strictly speaking, that the pairs of the individuals spaced by this length each other are more frequently observable than those expected from the chance distribution and this fact does not necessarily mean, or there is no proof supporting, that each one of the individuals from respective pairs of individuals is hooked aggregatively (or forming aggregations).

But it is one of the most fatal demerits of adopting the arrangement analysis that, when a little longer key-length is used, both the observed-values and the

estimated ones become far lower, which makes it impossible to obtain the results being suffered from scarcely any influence of accidental error from the examples in which not so many individuals are hooked, even if the hooked population-size in these examples is regarded to be large enough capable of getting the results somewhat free from the influence of accidental error when they are applied to the spacing method. And it seems to be worth while to describe the fact that it becomes very easy to count the observed-values in the arrangement analysis, in contrast with the fact that it is very troublesome to count those in the spacing one; while for the estimated-values it is *vice versa.*

Besides the above-mentioned theoretical comparison, as many as or more interest than that in them should be taken in what kinds of superficial and essential coincidences and differences are observable between the decoded patterns of the same examples through these two different analysis methods —— the arrangement analysis and the spacing one. Accordingly, the decoded pattern through the arrangement analysis will be compared with that through the spacing one, example by example. Here, exactly speaking, the structure at respective steps of analysis should be discussed; but, only the results of comparisons of the structures at the highest order observable within a whole length of a row will be described briefly in the below.

*Example Y* 1 : The arrangement analysis tells us that the population contains three clear schools and a doubtful one; and the clear ones are guessed to be hooked at the positions respectively from the 70th to the 102th, from the 176th to the 219th and from the 277th to the 319th baskets, while a doubtful one is from the 340th to the 358th basket. But the spacing analysis reveals that the hooked positions of the centers of the schools are guessed out to be at the positions around the 80th, the 200th, the 300th and the 350th baskets, respectively. Therefore, no difference is found out between the decoded structures through these two different analysis-methods.

*Example Y* 2 : The spacing analysis shows that there is a group of schools constituted of no more than five schools; and also the presence of two other schools is suggested, although the significance of one of which is doubtful. The probable hooked-positions of the schools pointed lastly through the spacing analysis (the positions around the 50th and the 150th baskets, in which the latter is doubtful) coincide with those guessed out through the arrangement analysis. But, for the detailed structure within the group of schools, we will find some differences. And they are thought to be due to the facts that, the hooked positions guessed out through the arrangement analysis together with Table 12 have less risk being suffered from the influence of accidental error, but those estimated through the spacing analysis bear some uncertainties due to the fact that not so appropriate clue to estimate the hooked positions as that in the arrangement analysis is found out, consequently there is no help for guessing the probable positions from the distances among the school-centers considering together with the positions of the most heavily-occupied lots of five consecutive basket width represented in Fig. 4.

*Example Y* 3 : A school of very weak contagiousness is pointed out from the results

of the spacing analysis; and this is thought to be covering the part from the 140th to the 315th basket and is constituted of neither less than three nor more than seven schools of the subordinate orders. But the arrangement analysis tells us that there are three schools hooked in the ranges respectively from the 146th to the 179th, from the 185th to the 205th and from the 245th to the 315th baskets; and the school hooked in the latter-most range is constituted of three schools of the subordinate orders of relatively large population-size. Therefore, any essential difference can not be found out between the decoded patterns through these two different analysis-methods.

*Example Y* 4 : Any school of large population-size and of strong contagiousness is not found out from the results of the arrangement analysis. Therefore, it is easily assumable preliminarily from this fact that no clear symptom suggesting the presence of any clear school of large population-size is expected to be observable in the results of the spacing analysis; and the actually obtained results through the spacing analysis support the above-mentioned prediction. And it may well be said that the spacing analysis is effectively applied to finding out the relation among the hooked positions of the schools only when the population contains any clear aggregation, otherwise the spacing analysis tells us the periodicity of the hooked positions of the individuals; thus, the facts deducible from the results of the spacing analysis and those from the arrangement one in this example are thought to represent the patterns to consider from quite the different points of views; consequently, the possibility of occurrence in such a difference as observed actually is easily recognizable.

*Example Y* 5 : The spacing analysis shows that the population contains two schools the centers of which are hooked at the positions around the 100th and the 350th baskets respectively. But the arrangement analysis shows that there is a school covering the part from the 265th basket to the hindmost one of the hauling of a row; besides this, the presence of three probable schools is suspected, and these schools are thought to cover the ranges respectively from the 95th to the 103th, from the 190th to the 205th and from the 216th to the 229th baskets. Thus, the hooked positions of the definite school and that of one of the probable ones are in common with the results of both analyses, while no corresponding symptom suggesting the presence of the probable one hooked at the position around the 200th basket is observable in the results of the spacing analysis; and this is thought to be, at least partly, due to the widely covering structure of the school hooked at the latter-most part and due to small population-size of all the schools including the definite one.

*Example Y* 6 : High occupied-rate causes a sharp decrease in the observed-values and the estimated ones in the interval analysis with increase in $k$, which makes it impossible to discuss the structure at the higher orders being suffered from scarcely any influence of accidental error in determining the key-length. Therefore, comparison is omitted. And I wish to describe here only the fact that considerably well coincident pattern with that assumable from Table 16, which is constructed of the original record based on the same idea as the arrangement analysis, is obtained from the re-

sults of the spacing analysis; and the similar consideration to the comparison of them, which should be treated in this paragraph, was already described in the paragraph of the results of the spacing analysis.

*Example Y* 7 : The arrangement analysis shows that the population contains four schools hooked at the parts respectively from the 127th to the 217th, from the 221th to the 262th, from the 301th to the 335th and from the 340th to the 377th baskets. But the distance between the first two schools and that between the last two are short as compared with their widths although they are separated clearly; consequently the spacing analysis is unable to find out these breaks of the schools but these schools are estimated to be continuous ones hooked at the parts around the 200th and the 350th baskets, respectively; while concerning the heavily-occupied part around the 50th basket, the presence of which is suspected only from the spacing analysis, no clear symptom suggesting the presence of it is found out from the results of the arrangement analysis. But when we consider a little strong influence of gradient together with the description in Example Y 5 in this paragraph, it seems to be better to give some significance to the symptom suggesting the presence of the group of the apparent clusters hooked in the range from the 19th to the 63th basket. Thus, it may be concluded that not so serious difference is observable between the decoded patterns through these two different analysis-methods.

*Example Y* 8 : The low occupied-rate and the short length of a row make it impossible to get high observed-values and the estimated ones in the arrangement analysis enough to get the results somewhat rid of the influence of accidental error. But the presence of three schools covering the parts respectively from the 77th to the 87th, from the 102th to the 122th and from the 147th to the 156th basket is guessed out. On the other hand, the spacing analysis suggests the presence of three schools hooked at the positions around the 20th, the 80th and the 150th baskets, respectively. Thus, concerning the presence of the schools located at the positions around the 80th and the 150th baskets, the same results are obtained through these two different analysis-methods. But, for the rests of it (the schools hooked at the positions around the 20th and the 110th baskets), no corresponding symptom suggesting the presence of them is found out in the results of each other's method. But examining more in detail, I found that the school hooked at the position around the 110th basket was constituted of rather scattered individuals and that the presence of the other was suspected from the high observed-value at $k = 13$ in the spacing analysis, which was for convenience' sake represented as high, but actually, did not reach the value worth while to give some significance. Thus, the significance of the presence of these schools causing the apparent differences is highly doubtful. Therefore, it may well be concluded that no serious difference can be found out between the decoded patterns through the different analysis-methods.

*Example Y* 9 : Like the preceding example, the low occupied-rate and the short length of a row make it impossible to obtain any structure of significance. And even if

dare to say committing against severe influence of accidental error, no true-cluster but few of those of small population-size can be pointed out through the arrangement analysis; and it is very hard to guess their hooked positions. Therefore, I can not tell whether any significant difference is observable between the decoded patterns through the different analysis-methods or not; moreover, if some apparent difference might be found out, any significance should hardly give them.

*Example Y* 10 : The arrangement analysis suggests the presence of two schools of not so strong contagiousness and constituted of 25 hooked-individuals and these schools are thought to be hooked at the positions around the 210th and the 270th baskets, respectively. And the same fact is also found out from the results of the spacing analysis. But the latter method tells us that there is another obscure school hooked at the position around the 345th basket; and Table 20 also suspects its presence. But we can hardly give any significance to the apparent difference of the observed-values in the arrangement analysis from the estimated ones, because none of the observed-values are so large as one. Therefore, I am obliged to keep it still pending to answer the question whether we can find any symptom from the arrangement analysis suggesting the presence of the school hooked at the position around the 345th basket or not, consequently to the question whether we can find out any significant difference in the decoded pattern through the arrangement analysis from that through the spacing one.

*Example Y* 11 : The spacing analysis shows that there are two schools or groups of schools hooked at the positions around the 25th and the 325th baskets. But, as represented in the exposition of particular example, the arrangement analysis tells us that as many as or more than 11 schools of not so strong contagiousness are scattered in a row, among which the hooked positions of the larger four are estimative but those of the rests of it are not estimative because it is very hard to distinguish the true ones from the false ones of respective population-size. But it can safely be said that the arrangement analysis suggests the presence of many schools distributed at the position around the 325th basket. On the other hand, the position around the 25th basket is one of the probable positions where a school constituted of eight hooked-individuals is hooked, meanwhile two schools constituted of each eight hooked-individuals among three are thought to be the true ones. Accordingly, it may also be safely said that any serious difference can not be found out between the decoded patterns through these two different analysis-methods.

*Example Y* 12 : The spacing analysis tells us that the population contains many schools rather scattered throughout a row. On the other hand, the arrangement analysis shows that the population contains seven or more schools, among which two or three are constituted of six hooked-individuals, one or two are of ten hooked-individuals; and all the hooked positions of these schools, except those of the larger three, are unable to be estimated. But it may well be said that all the probable positions of the schools, including the definite ones, are rather scattered throughout a row.

Accordingly, we may be able to conclude that not so serious difference can be observed between the results obtained through these two different analysis-methods.

Summarized results of the comparison : Generally speaking, any serious difference can not be observed between the decoded patterns through the spacing analysis and the arrangement one, especially in the examples in which the presence of some of the schools are clearly certified through both analysis-methods. But, for the examples in which the presence of some of the schools is not so clearly represented in the results of each or both of these two analysis-methods, some difference may be found out; and they are thought to be chiefly due to the uncertainty in the hooked positions of these schools guessed out through the spacing analysis. Moreover, for the examples in which the presence of no clear school is pointed out through the arrangement analysis, considerable differences in the decoded structures may be found out, because the facts deduced from the spacing analysis and those from the arrangement analysis represent the patterns to see from quite the different points of views due to the following reasons: the fact that the observed-value in the spacing analysis at $k$ largely exceeds corresponding theoretical one simply means that the pairs of the individuals spaced by $k$ each other are more frequently observable than expected from the chance distribution, but this fact has no proof supporting each one individual from respective pairs is hooked in some restricted parts, consequently the above-mentiond fact results in indicating the periodicity of the hooked positions of the individuals.

Accordingly, the arrangement analysis is thought to have many advantages. But when the distribution shows somewhat strong gradient, the arrangement analysis fades its ability, because of the following reasons: short intervals, consequently the lots constituted of successively arranged ones, have to be more frequently observable with approach to the final end of hauling of a row; accordingly, the key-length and the population-size have to be changed keeping some functional relations between the hooked positions; but it is very hard to take the influence of these facts on the arrangement analysis into consideration, and no correction for these influences is yet made in the theoretical-values in the arrangement analysis. Besides this, when the gears are heavily-occupied, both the observed-values and the estimated ones in the interval analysis decrease sharply with increase in $k$, which makes it impossible to find out any key-length in the arrangement analysis free from the influence of accidental error. But the same fact causes the high observed-values and the estimated ones in the spacing analysis, consequently high significance can be given to the deduced facts. Thus, each method has some merits effective under different conditions. Therefore, when we want to find out the distribution pattern more easily and clearly, it is desirable to adopt the arrangement analysis combining together with the spacing one.

## Trials for the exclusion of the influence of the presence of the buoy-lines upon the estimated-values in the arrangement analysis

As already mentioned in the introductive section in this part, the presence of the buoy-lines where no individual is able to be hooked has some influences upon the observed-values and the estimated ones in the arrangement analysis, but these influences are not yet taken into consideration to construct the above-mentiond formulae applicable to this method. Accordingly, here, I want to show some tracks of the construction of the formulae in which these influences are taken into consideration, although no complete formula practically applicable to is yet established.

In order to make it easier to proceed with the discussion, the influence of both the gradient of the occupied-rate due to that of soaking time and the difference in the occupied-rate of the hooks at the different depth levels due to the slackness of main-lines are put out of consideration; consequently, the occupied-rates of all the hooks are set to be the same. And a row of gears is set to be constituted of a connected series of $m$ baskets attached by four hooks a basket. And also the way of thinking is changed and the conception of total length of each lot, $K = 5A + R$, is introduced, because it is very difficult to take the influence of the presence of the buoy-lines into consideration extending to the same idea as in the constructing-process of the used formulae.

### 1. Track of the construction of the formulae representing the expectant number of the lots of $K$ long, constituted of a connected series of the intervals each of which is as long as or shorter than $k$ hook-intervals

#### 1) $k = 1$

(1) $K = 1$

i) When one starts to count the lot from the first hook in a certain basket, the lot ends to be counted in the second hook in the same basket (the rate of all the hooks in the lot occupied fully is as equal as $P^2$). Meanwhile, in order to be isolated this lot from the others, at least all the hooks located within both the preceding and succeeding $k$ hook-intervals to the lot must be kept unoccupied. Here, the hook preceding to the lot is the buoy-line; consequently there is no need to pay any attention to it, because the probability of keeping unoccupied is as equal as 1. And the succeeding hook to each lot is the third hook in the same basket and this also must be

kept unoccupied, and the probability of keeping unoccupied is as equal as $q$. Accordingly, the expectant number of such a lot observable in a row is $mP^2q$.

ii) When one starts to count the lot from the second hook in a certain basket, the lot ends to be counted in the third hook in the same basket; and the hook preceding to the lot is the first hook in the same basket, the unoccupied rate of which is as equal as $q$; but the hook succeeding to the lot is the last hook in the same basket, the unoccupied rate of which is also as equal as $q$. Accordingly, the expectant number of such a lot observable in a row is $mP^2q^2$.

iii) When one starts to count the lot from the third hook in a certain basket, the lot ends to be counted in the last hook in the same basket; and the preceding hook is the second one, the unoccupied rate of which is as equal as $q$; but the succeeding hook is a buoy-line, the unoccupied rate of which is as equal as 1. Accordingly, the expectant number of such a lot observable in a row is estimated to be $mP^2q$.

iv) And when one starts to count the lot from the last hook in a certain basket, the lot ends to be counted in the buoy-line. Accordingly, no lot fitted for this condition is theoretically expected to occur.

Therefore, the expectant number of the lots ($K=1$, $k=1$) is estimative summing the above-mentioned four terms, *i. e.*,

$$mP^2p(2+q).$$

(2) $K=2$

The lots fitted for this column are (1) those starting to be counted from the first hook and ending in the third hook and (2) those starting to be counted from the second hook and ending in the last hook in respective baskets. Consequently, the fully occupied rate of the hooks in each lot is as equal as $P^3$. But the preceding hook to the lot of the former group is the buoy-line, the unoccupied rate of which is as equal as 1; while the succeeding hook is the last one in the same basket, the unoccupied rate of which is as equal as $q$. And the preceding hook to the lot of the latter group is the first hook in the same basket, the unoccupied rate of which is as equal as $q$; while the succeeding one is the buoy-line, the unoccupied rate of which is as equal as 1. Accordingly, the expectant number of the lots ($K=2$, $k=1$) observable in a row is estimated to be as equal as $2mP^3q$.

(3) $K=3$

The lots fitted for this column are the fully occupied baskets. Accordingly, the expectant number is estimated to be as equal as $mP^4$.

(4) $K\geqq 4$

When $K\geqq 4$, the presence of the buoy-lines prohibits the occurrence in such a lot.

**2) $k\leq 2$**

All the formulae representing the expectant number of the lots of $K$ long with some unoccupied-hooks observable in a row, which will be described in the below,

are constructed from the formulae representing the expectant number of the fully occupied lots by correcting the influence of the presence of the unoccupied-hooks on the expectant numbers.

(1) $R=1$ $(K=5A+R)$

*i) The expectant number, when one starts to count the lot from the first hook in a certain basket*

The lot begins with the first hook in the *ith* basket, while ends in the second hook in the $(i+A)th$ one. Therefore, there are $(4A+2)$ hooks and $A$ buoy-lines in a lot. And the fully occupied rate of the hooks in the lot is $P^{(4A+2)}$. But, here, in order to be isolated this lot from the others, at least all the hooks located within both $k$ hook-interval widths preceding and succeeding to the lot must be kept unoccupied. The last hook in the $(i-1)th$ basket and a buoy-line are corresponding to the preceding part, while the third hook and the last one in the $(i+A)th$ basket are the succeeding part. Accordingly, when the lot is started to be counted from the other baskets than the first, three hooks and a buoy-line are located in the above-mentioned range and the rate of all the hooks kept unoccupied is $q^3$; while when one starts to count the lot from the first basket, the last hook in the $(i-1)th$ basket is protruded from a row, thus, there is no need to pay any attention to it, and the rate of all the hooks kept unoccupied becomes as equal as $q^2$. Accordingly, the expectant number of the occurrence in the fully occupied lots is

$$P^{(4A+2)}q^2(1+m-A-1q).$$

Then, let us correct the influence of the unoccupied hooks. The lot covers $(A+1)$ baskets; here, there is no hook in the last basket not necessarily to be occupied, while each one of the second hook and the third one in each of other $A$ baskets is not necessarily to be occupied. Accordingly, the admissible manner of the occurrence in the first unoccupied hook is $2A$, that in the second one is $2(A-1)$, .....and that in the $jth$ is $2(A-j+1)$. Thus, the admissible manner of the occurrence in $j$ unoccupied hooks (here, $j$ can not exceed $A$) is $2^j{}_AC_j$. But there are $4A$ inserted hooks, and the manner of picking up $j$ hooks among them is ${}_{4A}C_j$. Accordingly, the probability of occurrence in the admissible cases is $2^j\,{}_AC_j/{}_{4A}C_j$. And the expectant number is

$$2^j\frac{{}_AC_j}{{}_{4A}C_j}(1+\overline{m-A-1}q)P^{(4A+2-j)}q^{(j+2)}.$$

*ii) The expectant number, when one starts to count the lot from the second hook in a certain basket*

The lot begins to be counted with the second hook in the *ith* basket and ends in the third hook in the $(i+A)th$ one. Therefore, there are $(4A+2)$ hooks and $A$ buoy-lines in a lot. And the rate of all the hooks in the lot occupied fully is $P^{(4A+2)}$. The first hook in the *ith* basket and a buoy-line are located in the range preceding to the lot while the last hook in the $(i+A)th$ basket and a buoy-line are situated in the succeeding range, and the rate of all the hooks kept unoccupied is as equal as

$q^2$. Accordingly, the expectant number of occurrence in such a lot is $P^{(4A+2)}q^2(m-A)$.

Next, setting that $j$ hooks in the lot are kept unoccupied, let us give correction for it. The lot covers $(A+1)$ baskets, in which the third hook in the *ith* basket, the second hook in the $(i+A)th$ one and each one of the second hook and the third one in the inserted baskets are admissible to be not necessarily occupied. And for convenience' sake of explanation, I wish to treat the lots separately according to the number of the hooks kept unoccupied in the foremost basket and in the hindmost one of the lot. (1) When all the unoccupied hooks are located in the inserted baskets, the admissible manner of the occurrence in the first unoccupied hook is $2(A-1)$, that in the second one is $2(A-2)$ ····· and that in the $jth$ one is $2(A-j)$. But the manner of picking up $j$ hooks from $4A$ inserted hooks is ${}_{4A}C_J$. Accordingly, the probability of occurrence in the admissible cases is $2^J\frac{{}_{(A-1)}C_J}{{}_{4A}C_J}$. (2) When each one of the hooks in the foremost or the hindmost baskets admissible to be not necessarily occupied and other $(j-1)$ admissible ones in the inserted baskets are kept unoccupied, the admissible manner of the occurrence in the terminal one is ${}_2C_1=2$, while that in other $(j-1)$ hooks is $2^{(J-1)}{}_{(A-1)}C_{(J-1)}$; accordingly, there are $2^J{}_{(A-1)}C_{(J-1)}$ admissible manner; but the manner of picking up $j$ hooks is the same as that mentioned above. And the probability of occurrence in the admissible cases is $2^J\frac{{}_{(A-1)}C_{(J-1)}}{{}_{4A}C_J}$. (3) But when both of the hooks in the foremost and the hindmost baskets of the lot admissible to be not necessarily occupied and other $(j-2)$ ones in the inserted baskets are kept unoccupied, there is a manner keeping unoccupied both of the admissible hooks of the former group; while for the latter group, there are $2^{(J-2)}{}_{(A-1)}C_{(J-2)}$ admissible manner. But the manner of picking up $j$ hooks from $4A$ inserted ones is also ${}_{4A}C_J$. Accordingly, the probability of the occurrence in the admissible cases is $2^{(J-2)}\frac{{}_{(A-1)}C_{(J-2)}}{{}_{4A}C_J}$. And, the probability of the occurrence in the lots of $K$ long with $j$ unoccupied hooks and constituted of the intervals, each of which is as long as or shorter than two hook-intervals, is

$$2^J\frac{{}_{(A-1)}C_J}{{}_{4A}C_J}+2^J\frac{{}_{(A-1)}C_{(J-1)}}{{}_{4A}C_J}+2^{(J-2)}\frac{{}_{(A-1)}C_{(J-2)}}{{}_{4A}C_J}$$
$$=\frac{2^{(J-2)}{}_{(A-1)}C_J}{{}_{4A}C_J}\left\{\frac{4A}{A-J}+\frac{J(J-1)}{(A-J)(A-J+1)}\right\}.$$

Accordingly, the expectant number of the lots constituted of $(4A+2-j)$ hooked-individuals, each of which is spaced by an interval as long as or shorter than two hook-intervals from the adjoining ones, is

$$\frac{2^{(J-2)}{}_{(A-1)}C_J}{{}_{4A}C_J}\left\{\frac{4A}{A-J}+\frac{J(J-1)}{(A-J)(A-J+1)}\right\}(m-A)P^{(4A+2-J)}q^{(J+2)}.$$

*iii*) When one starts to count the lot from the third hook in a certain basket, the same results as those when one starts to count the lot from the first hook in the basket are obtained. And this fact may be easily recognizable, when we suppose to count the hook number and the basket number from the counter direction to the

hauling of the gears. That is to say,

$$2^J \frac{{}_AC_J}{{}_{4A}C_J}(1+\overline{m-A-1}q)P^{(4A+2-J)}q^{(J+2)}.$$

*iv*) But when one starts to count the lot from the last hook in a certain basket, the lot ends in a buoy-line; this means that no case fitted for this condition is theoretically supposed to occur.

Accordingly, the expectant number of the lots of $K=5A+1$ long constituted of $(4A+2-j)$ hooked-individuals, each of which is spaced by an interval as long as or shorter than two hook-intervals from the adjoining ones, is represented as follows, by summing up the above-mentioned formulae:

$$P^{(4A-2-J)}q^{(J+2)}\,2^J\,\frac{{}_AC_J}{{}_{4A}C_J}\left[2\left\{1+(m-A-1)q\right\}+(m-A)\left\{1+\frac{J(J-1)}{4A(A-J+1)}\right\}\right].$$

Notes:

1) $J$ can not exceed $A$.

2) All terms containing $J$ or $A$ should be positive, otherwise omitted.

(2) $R=2$

Through quite the same manner as those mentioned above, the expectant number, when one starts to count the lot from the first hook in the basket, is represented as follows:

$$P^{(4A+3-J)}q^{(J+1)}2^J\,\frac{{}_AC_J}{{}_{(4A+1)}C_J}\left\{1+(m-A-1)q\right\}\left\{1+\frac{J}{2(A-J+1)}\right\}.$$

That, when one starts to count the lot from the second hook in the basket, is also the same as this; while when one starts to count the lot from the third hook in the basket, the interval ends to be counted in a buoy-line and no lot fitted for this condition is theoretically expected to occur. But when one starts to count the lot from the last hook in the basket, the lot covers $(A+2)$ baskets and contains $(A+1)$ buoy-lines; therefore, substitute $(j-1)$ for $j$ for the purpose of adjusting the number of the occupied hooks in the lot, expectant number is represented as follows:

$$P^{(4A+3-J)}q^{(J+3)}2^{(J-1)}\,\frac{{}_AC_{(J-1)}}{{}_{4A}C_{(J-1)}}(m-A-1).$$

Accordingly, the expectant number of the lots of $K=5A+2$ long constituted of $(4A+3-j)$ hooked-individuals, each of which is spaced by an interval as long as or shorter than two hook-intervals from the adjoining ones, is represented as follows, by summing up these formulae:

$$P^{(4A+3-J)}q^{(J+1)}2^{(J-1)}\frac{{}_AC_J}{{}_{4A+1}C_J}\left[4\left\{1+\frac{J}{2(A-J+1)}\right\}\left\{1+(m-A-1)q\right\}\right.$$

$$\left.+(m-A-1)q^2\frac{(4A+1)}{(A-J+1)}\right].$$

Note: The same as (1) $R=1$.

(3) $R=3$

Through quite the same manner as that mentioned in the above, the expectant number of the lots of $K=5A+3$ long constituted of $(4A+4-j)$ hooked-individuals,

each of which is spaced by an interval as long as or shorter than two hook-intervals from the adjoining ones, is represented as follows:

When one starts to count the lot from the first hook in the basket:

$$2^{J}P^{(4A+4-J)}q^{(J+1)}\frac{(A+1)C_J}{(4A+2)C_J}\left\{1+(m-A-1)q\right\}$$

from the second hook: 0

from the third hook: $2^{(J-1)}P^{(4A+4-J)}q^{(J+3)}\frac{AC_{(J-1)}}{(4A+1)C_{(J-1)}}(m-A-1)$

from the last hook: The same as the above.

Accordingly, the expectant number of the lots of $K=5A+3$ long constituted of $(4A+4-j)$ hooked-individuals, each of which is spaced by an interval as long as or shorter than two hook-intervals from the adjoining ones, is

$$P^{(4A+4-J)}q^{(J+1)}2^{J}\frac{(A+1)C_J}{(4A+2)C_J}\left[\left\{1+(m-A-1)q\right\}+\frac{4A+2}{A+1}q^2\right].$$

(4) $R=4$

When one starts to count the lot from the first hook in the basket: 0

from the second hook:

$$2^{(J-1)}P^{(4A+5-J)}q^{(J+2)}\frac{AC_{(J-1)}}{(4A+2)C_{(J-1)}}\left\{1+\frac{(J-1)}{2(A-J+1)}\right\}(m-A-1)$$

from the third hook:

$$2^{(J-1)}P^{(4A+5-J)}q^{(J+3)}\frac{AC_{(J-1)}}{(4A+2)C_{(J-1)}}(m-A-1)$$

from the last hook: The same as that from the second hook.

Accordingly, the expectant number of the lots of $K=5A+4$ long constituted of $(4A+5-j)$ hooked-individuals, each of which is spaced by an interval as long as or shorter than two hook-intervals from the adjoining ones, is

$$P^{(4A+5-J)}q^{(J+2)}2^{(J-1)}\frac{AC_{(J-1)}}{(4A+2)C_{(J-1)}}(m-A-1)\left\{2+\frac{(J-1)}{(A-J+2)}+q\right\}.$$

(5) $R=0$

When one starts to count the lot from the first hook in the basket:

$$2^{J}P^{(4A+1-J)}q^{(J+2)}\frac{AC_J}{(4A-1)C_J}(1+\overline{m-A-1}q)$$

from the second hook:

$$2^{J}P^{(4A+1-J)}q^{(J+4)}\frac{AC_J}{(4A-1)C_J}\left\{1+\frac{J}{2(A-J+1)}\right\}(m-A)$$

from the third hook: The same as that from the second hook.

from the last hook: The same as that from the first hook.

Accordingly, the expectant number of the lots of $K=5A$ long constituted of $(4A+1-j)$ hooked-individuals, each of which is spaced by an interval as long as or shorter than two hook-intervals from the adjoining ones, is

$$P^{(4A+1-J)}q^{(J+2)}2^{(J+1)}\frac{AC_J}{(4A-1)C_J}\left[\left\{1+(m-A-1)q\right\}+\left\{1+\frac{J}{2(A-J+1)}\right\}(m-A)q^2\right].$$

### 3) $k \leqq 3$

When $k \leqq 2$, the hooks admissible to be not necessarily occupied are limited to be each one of the second hook and the third one in respective baskets, regardless of the manner of the presence of the hooks in the preceding basket and in the succeeding one actually kept unoccupied. But, in contrast with this, when $k \leqq 3$, the combinations of the hooks admissible to be not necessarily occupied are (1) buoy-line —— the first hook, (2) the second hook —— the third one and (3) the last hook —— buoy-line. But, here, when the hooks in a certain basket are actually kept unoccupied following the manner symbolized as (1), the last hook in the preceding basket and the second hook in the same basket are necessarily occupied; this means that the manner in the occurrence of the hooks in the preceding basket admissible to be not necessarily occupied is limited to be each one of the manner (1) or (2), and that of the same basket is also limited to the manner (3); when following (2), the presence of the unoccupied hooks causes no influence upon the manner of the admissible hooks to be not necessarily occupied in the preceding basket and in the succeeding one, while no other manner allows to occur in the same basket; while when following (3), no other manner than (1) allows to occur in the same basket, moreover the admissible manner of the hooks in the succeeding one not necessarily occupied is limited to be each one of the (2) and (3). Thus, the manner in occurrence of the hooks in a certain basket *admissible* to be not necessarily occupied is affected by the manner of the hooks in the preceding basket and in the same one *actually* kept unoccupied, and the manner of the presence of the hooks in a certain basket *actually* kept unoccupied affects the manner of the hooks in the succeeding basket *admissible* to be not necessarily occupied. Moreover, all the hooks admissible to be not necessarily occupied are not always kept unoccupied. Accordingly, if the formulae which can represent the expectant numbers were established, they may be too complicated to use on the actual computation or contain too much computation error. Moreover, when $k \leqq 4$, or longer, I am afraid that the formulae must be far complicated. In addition to these difficulties, even if these formulae were established, I am afraid that they are unable to apply to the actual analysis, because the lots, even the total number of which is preliminarily thought to be not so many, are divided into too many groups——respective $k$, $K$ and $j$ ——, which results in far lower observed-values and the estimated ones, consequently there are many risk to introduce severe influence of accidental error into decoding the pattern. Accordingly, the method, in which the lots are treated classifying into not so many groups, is desirable to be established. And an example of tracks based on this idea will be represented in the next paragraph.

## 2. Track of the construction of another estimation-method of the expectant number of the schools regarding the individuals spaced by an interval as long as or shorter than $k$ hook-intervals are aggregating each other

This method has some characteristics to resemble the interval analysis as well as the arrangement one. Therefore, there is no need to use together with the interval analysis, although not so many facts as those from the arrangement analysis can be drawn out.

Before entering into the construction of the formulae, I must give some preliminary consideration to the meanings of the interval between the individuals of $k$ hook-intervals wide. (1) When all the hooks located within at least $(k+1)$ hook-interval widths preceding to and succeeding to this interval are not occupied, this interval should be regarded as an isolated school constituted of a pair of hooked-individuals. (2) When there is no occupied-hook within at least $(k+1)$ hook-intervals preceding to the beginning of the interval and at the same time there is one or more occupied-hooks in $(k+1)$ hook-intervals succeeding to the end of the interval, this interval ought to be regarded as the beginning interval of a school, and (3) when *vice versa*, this interval should be regarded as the ending interval of a school. (4) But when there is at least each one or more occupied-hooks in $(k+1)$ hook-interval widths preceding to and succeeding to the interval, this interval should be regarded as the inserted interval of a school. Accordingly, the number of schools, when we set $k$ as the key-length to the school-formation, is estimated to be as many as $(1)+\frac{(2)+(3)}{2}$. And by the similar manner to the interval analysis, respective $k$ showing the maxima of increase in the number of schools per increase in $k$ should be regarded as the key-lengths to respective steps of school-formation. Then, the numbers of the apparent-schools and of the true ones at respective steps can be estimative, although any clue to estimating the population-size of respective schools can not be found out yet.

(1) $R=1$ (here, $k=5a+R$)

When one starts to count the interval from the first hook in the $ith$ basket, the interval ends to be counted in the second hook in the $(i+a)th$ basket (the hook number starting to count the interval is symbolized as 1, 2, 3 and 4 in the first letter of the formula-number). But the preceding range under consideration begins with the last hook in the $(i-a-1)th$ basket and the succeeding one ends in the last hook in the $(i+2a)th$ one. Therefore, (1) when $i$ is neither smaller than 1 nor larger than $(a+1)$, at least a part of the preceding range under consideration is protruded from a row, although all the parts of the interval itself and the succeeding range are situated within a row. (2) When $i$ is neither smaller than $(a+2)$ nor larger than $(m-2a)$, all the parts in the preceding range and the succeeding one to the interval

under consideration, naturally including the interval itself, are located within a row. (3) But when $i$ is neither smaller than $(m-2a+1)$ nor larger than $(m-a)$, at least a part of the succeeding range to the interval is protruded from a row, although whole part of the interval itself and the preceding range to it is not protruded from a row. And these three ranges of $i$ should be treated separately. The formulae corresponding to respective ranges of $i$ are symbolized by the second letter in the formula-number. But the last letter in each formula-number represents the classification of the intervals by their meanings described in the above. And the expectant numbers of respective conditions are estimative through the following formulae (for their constructing-processes, refer to those in respective analysis-methods already mentioned).

111 $P^2q^{4a}q^{4a+2}\sum_{i=0}^{a}q^{4i}$

112 $P^2q^{4a}(1-q^{4a+2})\sum_{i=0}^{a}q^{4i}$

113 $P^2q^{4a}q^{4a+2}\sum_{i=0}^{a}(1-q^{4i})$

114 $P^2q^{4a}(1-q^{4a+2})\sum_{i=0}^{a}(1-q^{4i})$

121 $(m-3a-1)P^2q^{4a}q^{4a+1}q^{4a+2}$

122 $(m-3a-1)P^2q^{4a}q^{4a+1}(1-q^{4a+2})$

123 $(m-3a-1)P^2q^{4a}(1-q^{4a+1})q^{4a+2}$

124 $(m-3a-1)P^2q^{4a}(1-q^{4a+1})(1-q^{4a+2})$

131 $P^2q^{4a}q^{4a+1}\sum_{i=0}^{a-1}q^{4i+2}$

132 $P^2q^{4a}q^{4a+1}\sum_{i=0}^{a-1}(1-q^{4i+2})$

133 $P^2q^{4a}(1-q^{4a+1})\sum_{i=0}^{a-1}q^{4i+2}$

134 $P^2q^{4a}(1-q^{4a+1})\sum_{i=0}^{a-1}(1-q^{4i+2})$

Accordingly, the partial sums of the expectant numbers of the intervals of respective meanings, when one starts to count the interval from the first hook in respective baskets, are represented as follows:

1·1 $$P^2q^{4a}\left[(m-3a-1)q^{4a+1}q^{4a+2}+q^{4a+2}\sum_{i=0}^{a}q^{4i}+q^{4a+1}\sum_{i=0}^{a-1}q^{4i+2}\right]$$

1·2 $$P^2q^{4a}\left[(m-3a-1)q^{4a+1}(1-q^{4a+2})\right.$$
$$\left.-(1-q^{4a+2})\sum_{i=0}^{a}q^{4i}+q^{4a+1}\sum_{i=0}^{a-1}(1-q^{4i+2})\right]$$

1·3 $$P^2q^{4a}\left[(m-3a-1)(1-q^{4a+1})q^{4a+2}\right.$$
$$\left.+q^{4a+2}\sum_{i=0}^{a}(1-q^{4i})+(1-q^{4a+1})\sum_{i=0}^{a-1}q^{4i+2}\right]$$

1·4 $$P^2q^{4a}\left[(m-3a-1)(1-q^{4a+1})(1-q^{4a+2})\right.$$
$$\left.-(1-q^{4a+2})\sum_{i=0}^{a}(1-q^{4i})-(1-q^{4a+1})\sum_{i=0}^{a-1}(1-q^{4i+2})\right]$$

When one starts to count the interval from the second hook in the *ith* basket, the interval ends to be counted in the third hook in the $(i+a)th$ one while the preceding range under consideration begins with the buoy-line located at the junction of the $(i-a-1)th$ basket and the $(i-a)th$ one, and that succeeding one ends also in another buoy-line located at the junction of the $(i+2a)th$ basket and the $(i+2a+1)th$ one, consequently the lot constituted of a connected series of these three intervals begins with the first hook in the $(i-a)th$ basket and ends in the last hook in the $(i+2a)th$ one. Thus, $i$ in column (1) is able to vary from 1 to $a$ and that in column (2) does from $(a+1)$ to $(m-2a)$, while that in column (3) is suffered from no influence. Accordingly, the formulae representing the expectant numbers of the intervals of respective conditions are obtained as follows:

211 $$P^2q^{4a}q^{4a+1}\sum_{i=0}^{a-1}q^{4i+1}$$

212 $$P^2q^{4a}(1-q^{4a+1})\sum_{i=0}^{a-1}q^{4i+1}$$

213 $$P^2q^{4a}q^{4a+1}\sum_{i=0}^{a-1}(1-q^{4i+1})$$

214 $$P^2q^{4a}(1-q^{4a+1})\sum_{i=0}^{a-1}(1-q^{4i+1})$$

221 $$P^2q^{4a}(m-3a)q^{4a+1}q^{4a+1}$$

222 $$P^2q^{4a}(m-3a)q^{4a+1}(1-q^{4a+1})$$

223 $P^2q^{4a}(m-3a)q^{4a+1}(1-q^{4a+1})$

224 $P^2q^{4a}(m-3a)(1-q^{4a+1})(1-q^{4a+1})$

231 $P^2q^{4a}q^{4a+1}\sum_{i=0}^{a-1}q^{4i+1}$

232 $P^2q^{4a}q^{4a+1}\sum_{i=0}^{a-1}(1-q^{4i+1})$

233 $P^2q^{4a}(1-q^{4a+1})\sum_{i=0}^{a-1}q^{4i+1}$

234 $P^2q^{4a}(1-q^{4a+1})\sum_{i=0}^{a-1}(1-q^{4i+1})$

Accordingly, the partial sums of the expectant numbers of the intervals of respective meanings, when one starts to count the interval from the second hook in respective baskets, are represented as follows:

2·1 $P^2q^{4a}\left[(m-3a)(q^{4a+1})^2+2q^{4a+1}\sum_{i=0}^{a-1}q^{4i+1}\right]$

2·2 $P^2q^{4a}\left[(m-3a)q^{4a+1}(1-q^{4a+1})\right.$

$\left.+q^{4a+1}\sum_{i=0}^{a-1}(1-q^{4i+1})+(1-q^{4a+1})\sum_{i=0}^{a-1}q^{4i+1}\right]$

2·3 $P^2q^{4a}\left[(m-3a)q^{4a+1}(1-q^{4a+1})\right.$

$\left.-q^{4a+1}\sum_{i=0}^{a-1}(1-q^{4i+1})-(1-q^{4a+1})\sum_{i=0}^{a-1}q^{4i+1}\right]$

2·4 $P^2q^{4a}\left[(m-3a)(1-q^{4a+1})^2+2(1-q^{4a+1})\sum_{i=0}^{a-1}(1-q^{4i+1})\right]$

When one starts to count the interval from the third hook in respective baskets, the following results are obtained:

311 $P^2q^{4a}q^{4a+1}\sum_{i=0}^{a-1}q^{4i+2}$

312 $P^2q^{4a}(1-q^{4a+1})\sum_{i=0}^{a-1}q^{4i+2}$

313 $P^2q^{4a}q^{4a+1}\sum_{i=0}^{a-1}(1-q^{4i+2})$

$$314 \quad P^2q^{4a}(1-q^{4a+1})\sum_{i=0}^{a-1}(1-q^{4i+2})$$

$$321 \quad (m-3a-1)\,P^2q^{4a}q^{4a+2}q^{4a+1}$$

$$322 \quad (m-3a-1)\,P^2q^{4a}q^{4a+2}(1-q^{4a+1})$$

$$323 \quad (m-3a-1)\,P^2q^{4a}(1-q^{4a+2})q^{4a+1}$$

$$324 \quad (m-3a-1)\,P^2q^{4a}(1-q^{4a+2})\,(1-q^{4a+1})$$

$$331 \quad P^2q^{4a}q^{4a+2}\sum_{i=0}^{a}q^{4i}$$

$$332 \quad P^2q^{4a}q^{4a+2}\sum_{i=0}^{a}(1-q^{4i})$$

$$333 \quad P^2q^{4a}(1-q^{4a+2})\sum_{i=0}^{a}q^{4i}$$

$$334 \quad P^2q^{4a}(1-q^{4a+2})\sum_{i=0}^{a}(1-q^{4i})$$

Accordingly, the partial sums of the expectant numbers of the intervals of respective meanings, when one starts to count the interval from the third hook in respective baskets, are represented as follows:

$$3\cdot1 \quad P^2q^{4a}\left[(m-3a-1)\,q^{4a+2}q^{4a+1}+q^{4a+1}\sum_{i=0}^{a-1}q^{4i+2}+q^{4a+2}\sum_{i=0}^{a}q^{4i}\right]$$

$$3\cdot2 \quad P^2q^{4a}\left[(m-3a-1)\,q^{4a+2}(1-q^{4a+1})\right.$$
$$\left.+(1-q^{4a+1})\sum_{i=0}^{a-1}q^{4i+2}+q^{4a+2}\sum_{i=0}^{a}(1-q^{4i})\right]$$

$$3\cdot3 \quad P^2q^{4a}\left[(m-3a-1)\,(1-q^{4a+2})q^{4a+1}\right.$$
$$\left.+q^{4a+1}\sum_{i=0}^{a-1}(1-q^{4i+2})+(1-q^{4a+2})\sum_{i=0}^{a}q^{4i}\right]$$

$$3\cdot4 \quad P^2q^{4a}\left[(m-3a-1)\,(1-q^{4a+2})\,(1-q^{4a+1})\right.$$
$$\left.+(1-q^{4a+1})\sum_{i=0}^{a-1}(1-q^{4i+2})+(1-q^{4a+2})\sum_{i=0}^{a}(1-q^{4i})\right]$$

But when one starts to count the interval from the last hook in respective

baskets, the interval ends to be counted in the buoy-line; thus, no interval is theoretically expected to occur.

Accordingly, the formulae representing the expectant numbers of the intervals of respective meanings observable in a row are as follows:

(1) $$2P^2q^{4a}\left[(m-3a-1)\,q^{4a+2}q^{4a+1}+q^{4a+2}\sum_{i=0}^{a}q^{4i}+q^{4a+1}\sum_{i=0}^{a-1}q^{4i+2}\right]$$
$$+P^2q^{4a}\left[(m-3a)\,(q^{4a+1})^2+2q^{4a+1}\sum_{i=0}^{a-1}q^{4i+1}\right]$$

(2) $$P^2q^{4a}\left[(m-3a-1)\left\{(1-q^{4a+2})\,q^{4a+1}+q^{4a+2}(1-q^{4a+1})\right\}\right.$$
$$+(m-3a)\,(1-q^{4a+1})q^{4a+1}+q^{4a+1}\left\{\sum_{i=0}^{a-1}(1-q^{4i+2})+q\sum_{i=0}^{a}(1-q^{4i})\right.$$
$$\left.+\sum_{i=0}^{a-1}(1-q^{4i+1})\right\}+\left\{(1-q^{4a+1})\sum_{i=0}^{a-1}q^{4i+1}+(1-q^{4a+2})\sum_{i=0}^{a}q^{4i}\right.$$
$$\left.\left.+(1-q^{4a+1})\sum_{i=0}^{a-1}q^{4i+2}\right\}\right]$$

(3) The same as the above.

(4) $$2P^2q^{4a}\left[(m-3a-1)\,(1-q^{4a+1})\,(1-q^{4a+2})+(1-q^{4a+2})\sum_{i=0}^{a}(1-q^{4i})\right.$$
$$\left.+(1-q^{4a+1})\sum_{i=0}^{a-1}(1-q^{4i+2})\right]$$
$$+P^2q^{4a}\left[(m-3a)\,(1-q^{4a+1})^2+2(1-q^{4a+1})\sum_{i=0}^{a-1}(1-q^{4i+1})\right]$$

And by the similar manner to that mentioned above, the formulae applicable to other $R$ are obtained as follows:

(2) $R=2$

1·1 $$P^2q^{4a+1}\left[(m-3a-2)\,q^{4a+2}q^{4a+2}+q^{4a+2}\left\{\sum_{i=0}^{a}q^{4i}+\sum_{i=0}^{a}q^{4i+1}\right\}\right]$$

1·2 $$P^2q^{4a+1}\left[(m-3a-2)\,q^{4a+2}(1-q^{4a+2})\right.$$
$$\left.+(1-q^{4a+2})\sum_{i=0}^{a}q^{4i}+q^{4a+2}\sum_{i=0}^{a}(1-q^{4i+1})\right]$$

1·3 $$P^2q^{4a+1}\left[(m-3a-2)\,(1-q^{4a+2})q^{4a+2} + q^{4a+2}\sum_{i=0}^{a}(1-q^{4i}) + (1-q^{4a+2})\sum_{i=0}^{a}q^{4i+1}\right]$$

1·4 $$P^2q^{4a+1}\left[(m-3a-2)\,(1-q^{4a+2})\,(1-q^{4a+2}) + (1-q^{4a+2})\left\{\sum_{i=0}^{a}(1-q^{4i}) + \sum_{i=0}^{a}(1-q^{4i+1})\right\}\right]$$

2·1 = 1·1

2·2 = 1·3

2·3 = 1·2

2·4 = 1·4

3·1 = 3·2 = 3·3 = 3·4 = 0

4·1 $$P^2q^{4a}q^{4a+3}\left[(m-3a-1)\,q^{4a+3} + 2\sum_{i=0}^{a-1}q^{4i+3}\right]$$

4·2 $$P^2q^{4a}\left[(m-3a-1)\,q^{4a+3}(1-q^{4a+3}) + (1-q^{4a+3})\sum_{i=0}^{a-1}q^{4i+3} + q^{4a+3}\sum_{i=0}^{a-1}(1-q^{4i+3})\right]$$

4·3 = 4·2

4·4 $$P^2q^{4a}(1-q^{4a+3})\left[(m-3a-1)\,(1-q^{4a+3}) + 2\sum_{i=0}^{a-1}(1-q^{4i+3})\right]$$

Accordingly,

(1) $$2P^2q^{4a+1}q^{4a+2}\left[(m-3a-2)\,q^{4a+2} + \sum_{i=0}^{a}q^{4i} + \sum_{i=0}^{a}q^{4i+1}\right] + P^2q^{4a}q^{4a+3}\left[(m-3a-1)\,q^{4a+3} + 2\sum_{i=0}^{a-1}q^{4i+3}\right]$$

(2)=(3) $$P^2q^{4a+1}\left[2(m-3a-2)\,(1-q^{4a+2})q^{4a+2} + q^{4a+2}\left\{\sum_{i=0}^{a}(1-q^{4i}) + \sum_{i=0}^{a}(1-q^{4i+1})\right\} + (1-q^{4a+2})\left\{\sum_{i=0}^{a}q^{4i} + \sum_{i=0}^{a}q^{4i}\right\}\right] + P^2q^{4a}\left[(m-3a-1)\,q^{4a+3}(1-q^{4a+3})\right.$$

$$+(1-q^{4a+3})\sum_{i=0}^{a-1} q^{4i+3}+q^{4a+3}\sum_{i=0}^{a-1}(1-q^{4i+3})\Big]$$

(4) $$2P^2q^{4a+1}(1-q^{4a+2})\Big[(m-3a-2)\ (1-q^{4a+2})+\sum_{i=0}^{a}(1-q^{4i})+\sum_{i=0}^{a}(1-q^{4i+1})\Big]$$

$$+P^2q^{4a}(1-q^{4a+3})\Big[(m-3a-1)\ (1-q^{4a+3})+2\sum_{i=0}^{a-1}(1-q^{4i+3})\Big]$$

(3) $R=3$

(1) $$2P^2q^{4a+1}q^{4a+3}\Big[(m-3a-2)\ q^{4a+3}+\sum_{i=0}^{a-1} q^{4i+3}+\sum_{i=0}^{a} q^{4i+2}\Big]$$

$$+P^2q^{4a+2}q^{4a+3}\Big[(m-3a-2)\ q^{4a+3}+2\sum_{i=0}^{a} q^{4i}\Big]$$

(2)=(3) $$P^2q^{4a+1}\Big[2(m-3a-2)\ q^{4a+3}(1-q^{4a+3})+q^{4a+3}\Big\{\sum_{i=0}^{a}(1-q^{4i+2})$$

$$+\sum_{i=0}^{a-1}(1-q^{4i+3})\Big\}+(1-q^{4a+3})\Big\{\sum_{i=0}^{a-1} q^{4i+3}+\sum_{i=0}^{a} q^{4i+2}\Big\}\Big]$$

$$+P^2q^{4a+2}\Big[(m-3a-2)\ q^{4a+3}(1-q^{4a+3})$$

$$+(1-q^{4a+3})\sum_{i=0}^{a} q^{4i}+q^{4a+3}\sum_{i=0}^{a}(1-q^{4i})\Big]$$

(4) $$2P^2q^{4a+1}(1-q^{4a+3})\Big[(m-3a-2)(1-q^{4a+3})+\sum_{i=0}^{a-1}(1-q^{4i+3})+\sum_{i=0}^{a}(1-q^{4i+2})\Big]$$

$$+P^2q^{4a+2}(1-q^{4a+3})\Big[(m-3a-2)(1-q^{4a+3})+2\sum_{i=0}^{a}(1-q^{4i})\Big]$$

(4) $R=4$

(1) $$P^2q^{4a+2}q^{4a+4}\Big[3(m-3a-3)\ q^{4a+4}+2\sum_{i=0}^{a} q^{4i+1}+2\sum_{i=0}^{a} q^{4i+2}+2\sum_{i=0}^{a} q^{4i+3}\Big]$$

(2)=(3) $$P^2q^{4a+2}\Big[3(m-3a-3)\ q^{4a+4}(1-q^{4a+4})+(1-q^{4a+4})\Big\{\sum_{i=0}^{a} q^{4i+1}$$

$$+\sum_{i=0}^{a} q^{4i+2}+\sum_{i=0}^{a} q^{4i+3}\Big\}+q^{4a+4}\Big\{\sum_{i=0}^{a}(1-q^{4i+1})+\sum_{i=0}^{a}(1-q^{4i+2})$$

$$+\sum_{i=0}^{a}(1-q^{4i+3})\Big\}\Big]$$

(4) $$P^2q^{4a+2}(1-q^{4a+4})\Big[3(m-3a-3)(1-q^{4a+4})+2\sum_{i=0}^{a}(1-q^{4i+1})$$
$$+2\sum_{i=0}^{a}(1-q^{4i+2})+2\sum_{i=0}^{a}(1-q^{4i+3})\Big]$$

(5) $R=0$

(1) $$2P^2q^{4a-1}\Big[q^{4a+1}\Big\{(m-3a)(q^{4a}+q^{4a+1})+\sum_{i=0}^{a-1}q^{4i}+\sum_{i=0}^{a-1}q^{4i+1}$$
$$+\sum_{i=0}^{a-1}q^{4i+2}\Big\}+q^{4a}\sum_{i=0}^{a-1}q^{4i+3}\Big]$$

(2)=(3) $$P^2q^{4a-1}\Big[(1-q^{4a+1})\Big\{(m-3a)(q^{4a}+2q^{4a+1})+\sum_{i=0}^{a-1}q^{4i}$$
$$+\sum_{i=0}^{a-1}q^{4i+1}+\sum_{i=0}^{a-1}q^{4i+2}\Big\}+q^{4a}\sum_{i=0}^{a-1}(1-q^{4i+3})+q^{4a+1}\Big\{\sum_{i=0}^{a-1}(1-q^{4i})$$
$$+\sum_{i=0}^{a-1}(1-q^{4i+1})+\sum_{i=0}^{a-1}(1-q^{4i+2})\Big\}+(1-q^{4a})\Big\{(m-3a)q^{4a+1}+\sum_{i=0}^{a-1}q^{4i+3}\Big\}\Big]$$

(4) $$2P^2q^{4a-1}\Big[(1-q^{4a+1})\Big\{(m-3a)(2-q^{4a}-q^{4a+1})+\sum_{i=0}^{a-1}(1-q^{4i})$$
$$+\sum_{i=0}^{a-1}(1-q^{4i+1})+\sum_{i=0}^{a-1}(1-q^{4i+2})\Big\}+(1-q^{4a})\sum_{i=0}^{a-1}(1-q^{4i+3})\Big]$$

Thus, the expectant numbers of the schools at respective $k$, in which the influence of the presence of the buoy-lines is taken into consideration, become estimative; and this series of the estimated-values and the observed ones corresponds to $\sum_{W=1}^{N-1}\Psi_{(W+k)}$. Accordingly, the influence of the presence of the buoy-lines on total number of schools at respective $k$ can be corrected; but there is no clue to solve a question how the correction-term is fractionated into respective $W$, against the fact that considerably much effort is obliged to be paid to the computation of this series of theoretical-values. Moreover, if the influences of the slackness of the main-lines and of the gradient of the soaking time on the occupied-rates of the hooks were taken into consideration, the computation becomes, if possible, far more troublesome; this comes to introduce severe computation error, the magnitude of which is sometimes supposed to exceed or reach that of the correction-term. And, in addition to the above-mentioned facts, the theoretical-values of the arrangement analysis themselves have many other sources of error, the influences of which remain untouched; therefore, it becomes doubtful whether a correction bearing much risk to introduce such high computation-error as this should be tried paying much effort or not. And, here, I want to

dare to describe the fact that this series of works is attempted to finding out the distribution pattern of the tuna projected along long-line to see from ecological point of view; and, I am afraid that it has much risk to loose the sight of the subject of this series of works to pay too much mathematical effort for seaking about better methods, although it is naturally desirable to use the method bearing less sources of error and introducing less computation error. Therefore, neither any actual computation using this series of formulae is tried, nor any further effort is paid to finding out any other advanced method, in which the influence of any other source of error is taken into consideration.

## Discussion and Conclusion

Applying the similar method to that used in this report, I analyzed the distribution patterns of the salmons projected along a row of drift-net observed in the waters south of the Aleutian Islands and came to the conclusion that the salmons did not form any school other than the considerably dispersed ones (MAÉDA, 1953). And the facts supporting well this conclusion were reported by UCHIHASHI (1953) through the detailed comparative morphological studies on the fish brains in relation to their habits and by HASHIMOTO and MANIWA (1956) through the echo-sounder specially designed for the purpose of finding out even a single individual. Furthermore, recently, TAGUCHI (1959) analyzed the frequency distribution of catch by respective sections in a row of salmon drift-net and that of the daily catch by respective boats, and he also came to the conclusion well supporting the above-mentioned results.

On the other hand, I had constructed the series of formulae of sequence analysis based on the theory of probability, in which most of the peculiar conditions specific to long-line gears are fulfilled (called spacing analysis), and the distribution patterns of three species of tuna of commercial importance projected along a row of long-line gears were analyzed by using these formulae. The results tell us that the tuna forms schools of various scales of such weak contagiousness that the distribution to consider a row as a whole does not differ so much from the chance distribution (MAÉDA, 1960). And the analyses by using the more advanced methods —— the interval analysis and the arrangement one ——, which are illustrated in Parts Ⅱ and Ⅲ of this report, also reveal the structures quite coincident with those through the spacing analysis. And these results of analyses are not so different from the structures suggested by MURPHY and ELLIOT (1954) through the analysis method of the most probable number of runs. IWASHITA (M. S.) recorded the distributions of deep swimming tuna in its fishing ground by an echo-sounder specially deviced out capable of finding out a single individual of tuna. The outline of his records suggests the presence of some aggregations, but the estimation on the intervals between the individuals from ship's speed during the recording tells us that the fishes ——, most of which are assumed, from the catch, to be the yellow-fin tuna and the big-eye tuna —— do not form any school but the considerably dispersed ones. Thus, it may well be concluded that the analysis-methods proposed in this series of works can lead us to the suggestion on school-formation of some confidence; and also it may well be considered that pelagic fish swimming in the ocean such as the salmons and the tunas form considerably dispersed schools.

And, for the purpose of giving some consideration to the reasons why these pelagic-fishes do not form any school other than considerably dispersed ones in their usual habitat——in the off-shore——, let us examine on the relation of the schooling-tendencies of some common pelagic-fishes to their food habits, the distribution of their

prey, that of their predators, their body length, their swimming ability, fishing method by which they are caught.

The anchovy is the smallest of all the surface swimmers commonly observable and measures 9～13 cm in body length; consequently, this is hardly thought to be quick and active-swimmer. We can rather frequently observe its dense school. The remarkable variability in catch by beach-seine and by small purse-seine supports the formation of small but dense schools. Its foods, phyto- and zoo-plankton, are thought to be distributed rather densely in its habitat; accordingly, dense schooling does not cause any obstacle to get their foods. Moreover, this fish is thought to be taken by almost every pelagic-fish of medium- and large-size; accordingly, the dense schooling may be more profitable to survive well against severe attack by its predators.

The sardine is a little larger than the anchovy and measures 10～25 cm in body length; this is thought to be able to swim a little more quickly than the latter and can swim *ca.* 3.3 miles per day (this means neither the maximum speed, nor actually swimming one, but indicates the average of daily pass estimated from its migration; therefore, I am afraid it is not suitable to show such a value for the material of the discussion treated here). This fish is also the plankton-feeder, but the proportion of zooplankton to total plankton taken by this fish is larger than that of the anchovy; meanwhile, it is evident that the zooplankton is distributed far less densely than phytoplankton, even if the former is distributed considerably dense in the coastal waters; on the other hand, increase in size induces to lessen the risk to be attacked by any other fish. This fish is also caught by beach-seine and by small purse-seine, although the scale of the gears for this fish is somewhat larger than that for the anchovy; and the remarkable variability of catch suggests the formation of a little large and dense schools. Meanwhile, in some districts, drift-net is used to catch the grown-up individuals of this fish; this may well be thought to be more or less related to a little dispersed structure of its schools, although it is self-evident that a little large size, which naturally induces to rise in the market price, has clearly some relations to this fishing method. Thus, it may well be thought that the sardine forms large and dense schools but its aggregative tendency is not so strong as that of the anchovy. Here, the dense schooling is hardly thought to cause any obstacle but is thought to be more profitable to survive well.

The horse mackerel and the mackerel are the most common on-shore fishes swimming in surface layer and situated at a little higher trophic levels than the sardine. The horse mackerel is as large as or a little larger than the sardine in body length. The mackerel is also a little larger than the sardine and measures about 40 cm in body length; this is thought to be able to swim 0.2～10 miles per day. The purse-seine is the most usual method to catch these fishes. But it is necessary to concentrate them by fish-gathering lamp or rarely by ground bait before hauling, against the fact that the gears for them are far larger than those for the anchovy and the sardine. And the catch deviates severely haul by haul, day by day or seiner by seiner. These facts seem to suggest the formation of large but somewhat dis-

persed schools. On the other hand, these fishes are also caught by long-line and drift-net and those gathered by fish-gathering lamp or by ground bait are angled up; these differences in fishing method are chiefly due to the difference in their food habits as well as size which induces to rise in the market price, but may have some relations to the dispersed structure of their schools. The scarcity of the fishes attacking them does not cause any obstacle to form the dispersed schools.

Another large on-shore-surface-swimmer is the yellowtail. This fish is far larger than the above-mentioned four fishes, and attains to about 80 cm in body length; this can swim far rapidly and its swimming ability is estimated to be a large value such as from 10 to 50 miles per day. But this fish is thought to be more beneficial to forming considerably dense schools than to swimming in scatter, against its considerable ability to swim and its large size, because of the dense schooling of its principal prey, the anchovy. This fish occasionally visits the waters nearer than 1 km off the coast. The dishomogeneity in its environmental conditions may contribute to forming dense school. Major of this fish is caught by set-net; this fact and the remarkable variability in catch support the large- and dense-school formation. Meanwhile, some of catch are brought from domesticate fishing, angling and trolling; this suggests the presence of some scattered individuals.

The salmons, which are the typical surface-swimmers living in the subpolar off-shore waters, are a little smaller than the yellowtail and are as large as from 40 to 60 cm in body length; consequently, their swimming ability is a little inferior to the yellowtail and they are estimated to be able to swim $7 \sim 30$ miles per day. The dense-school formation in the coastal waters, where extremely dense prey and considerable dishomogeneity in the environmental conditions are expected, is suggested from the good catch by purse-seine and by set-net and the severe variability in them. In off shore, however, the environmental conditions are thought to be far homogeneous than that of on shore and each of their prey —— large-sized zooplankton, small squids and some fish fry —— is thought neither to form clear schools nor to be distributed so densely. These facts are well thought to induce the salmons to form such a scattered structure as suggested from many records and analyses on the distribution along drift-net or along long-line and on the variability in catch by these fishing methods. And a little strong swimming-ability may more or less contribute to showing such a dispersed structures.

The skipjacks and the albacore may well be thought to be the fishes in the mid- and low-latitudal waters corresponding to the salmons in the higher-latitudal waters. The skipjacks, which are about 50 cm in body length, feed chiefly on zooplankton and partly on small fishes and squids. As easily acceptable from the fact that major of skipjacks is caught chiefly by angling and partly by huge purse-seine, it is evident that this fish forms considerably large and compact schools even in the off-shore. But those caught by these methods are the migrating schools chiefly constituted of the individuals not older than four ages. Moreover, the profitable fishing-grounds are found only around the polar front or any other convergence line, where the environmental

conditions may be considerably dishomogeneous and the distribution of prey is rather dense and considerably dishomogeneous. Nearly the similar suggestions to those mentioned above may give the young albacore, which is not longer than 60 cm in body length. But the grown-up albacore, inhabiting in lower-latitudal waters than the young, is caught chiefly by long-line. But there is no proper fishing-method of catching the grown-up skipjacks, although they are occasionally caught by tuna long-line. Therefore, the grown-up individuals of these fishes are thought to be distributed forming scattered structure. The environmental conditions of their fishing ground in the low-latitudal off-shore waters are, roughly speaking, more homogeneous than those in the young's habitats, moreover, their prey, chiefly large zooplankton, are far less densely distributed in such a waters. These fishes are hardly thought to be so frequently attacked by any other animal. Therefore, the scattered structure is thought to be more profitable to survive well, and not so many obstacles are supposed to be introduced by scattered structure.

The young individuals of the yellow-fin tuna and the big-eye tuna in the coastal waters are caught by huge purse-seine. This suggests that these fishes form schools at young stage. But their grown-up individuals are caught by long-line in the low-latitudal off-shore waters. And analyzing their distribution patterns projected along long-lines, I came to such a conclusion that these fishes were distributed forming extremely scattered schools of negligibly weak contagiousness. The grown-up individuals of these fishes are very large (about as long as 150 cm in body length) and are thought to be active swimmers; consequently it is not so hard to assume that they require considerably wide living-sphere. The principal component of their prey are large zooplankton, small file fishes, small puffers and any other fish, all of which are thought neither to form schools nor to be distributed densely, but are well thought to be scattered less densely in the low-latitudal off-shore waters. Moreover, freely swimming tunas are thought to be attacked by scarcely any predator other than killer whale which is not so abundant animal, although the hooked ones are rather frequently attacked by sharks and other voracious predators. And the environmental conditions in their fishing grounds are hardly thought to be so dishomogeneous as those in the on-shore waters. Therefore, they are thought to form extremely scattered schools of negligibly weak contagiousness except some rare and exceptional cases mentioned in the introduction of the first report of this series, and it is easily supposable that the scattered structure does not cause any obstacle, but causes some profits to survive well.

The largest surface-swimmers in the low-latitudal off-shore waters, the marlins and the spear fishes, are thought to be situated at higher trophic level and able to swim more actively than the tuna and any other fish; and these facts induce to lessen the risk attacked by any other animal and to require wider living-sphere. And deducing from the relation of the distribution pattern to size of fish, density and distribution patterns of prey and predator, swimming ability, *etc.*, I guessed that these fishes were thought to show such a extremely scattered structure as that appli-

cable to harpooning.

The porpoise, the killer whale and many other marine mammals are the typical examples forming schools in the ocean; but they are not the Pisces, but are the Mammalia. Therefore, they are expected to be different in many habits from the fishes; and we can hardly compare their schooling-tendency with those of the fishes.

## Summary

1. It is one of the principal subjects of this report to show the correlation of the hooked positions between the individuals of any two species of tuna among the yellow-fin tuna, the big-eye tuna and the albacore. Another importance of this report is given to the discussion on the analysis on the distribution patterns of the tuna projected along long-line gears through the interval analysis and the arrangement one, which are constructed from the spacing method giving some theoretical improvement, against the fact that the analysis through the spacing method was the subject of the first report of this series of works.

2. The data used for the present study was offered by the Dai-fuji Maru obtained in the waters central part of the Indian Ocean during the period from April 5th to 16th, 1955. The sketch chart of the fishing ground is shown in Fig. 1; and the amount of used gears and the catch composition at each station are given in Table 1. And the outline of the gears and of the operation are described in the section "The method for collecting the data".

## Part I Correlation Analysis

(Including the spacing analysis, as a preliminary procedure)

3. It is one of the principal subjects of this report to know the correlations of the hooked positions between the individuals of any two species of tuna among the three. But those to consider with large scale are easily presupposable from the distribution patterns of the hooked-individuals of respective species, although those observable within a short range are not easily assumable, despite of much ecological interest and importance. On the other hand, it is also one of the principal subjects to show the decoded patterns through the interval analysis and the arrangement one; accordingly, I must examine what kinds of superficial and fundamental differences and coincidences in the decoded patterns are caused by the differences in the basic assumptions in the newly-added analysis-methods from the spacing one. Therefore, I cannot help describing the results of the decoded patterns of the examples used in this report through the spacing analysis as a preliminary procedure, although many examples analyzed actually through this method and the consideration about the results and the errors contained in them were represented in detail in the first report.

4. The theoretical-values of this reports are computed from the formulae, in which the influence of the gradient of the occupied-rates due to that of the soaking time and that of the periodicity of the occupied-rates due to that of the fishing depths of the hooks are taken into consideration. But their constructing-processes are omitted, because they were already described minutely in the first report.

5. In the first report, the projected distribution patterns were analyzed by adopting three unit-lengths for the decoding, which were five consecutive basket, one basket and one hook-interval widths. But, in this report, two other series of analyses, in which ten and two consecutive basket widths are adopted as the unit-lengths, are added to them.

6. All $\Delta p$ used in this report are computed, as discussed in the section "Consideration upon the error in the theoretical values" of the first report, from the regression equation of catch on lot number of 20 consecutive basket width, then $P$ is from the equation, $\sum_{i=1}^{M}(P+i\Delta P)=N$, so as to get the constants with the computation error as small as possible.

7. The distribution patterns of three species of tuna projected along each of 12 rows of gears are analyzed through the spacing method. And summarizing the results, I want to describe the following patterns as the general structures of respective species.

8. There is no example of the yellow-fin tuna clearly showing the self-spacing pattern, but the hooked-individuals in each example form the schools of several-fold contagiousness. And the common structure of the highest order observable within a row to all the examples is the schools, the magnitude of width of which is 2 km order. But, in a half number of the examples, the schools of the above-mentioned order further form the schools of not so strong contagiousness each extending from 10 to 30 km.

9. Generally speaking, the hooked density of the big-eye tuna in each example can not attain to the value as high as an individual per 10 consecutive baskets; accordingly, no structure of some significance but the following tendencies can be deduced out: relatively clear school-formation is found out in about a half number of the examples, although the population-size of each school is not so large; while the examples of the rests of them suspect the self-spacing pattern.

10. Like the big-eye tuna, the poor catch of the albacore by each row makes it impossible to get any pattern of some significance; while, for convenience' sake, only the following patterns are described as the general tendency: this species is inclined to form the schools covering a width longer than a half length of a row or sometimes nearly as long as a whole length, in which the individuals are hooked rather self-spacingly.

11. Then, the correlation of the hooked positions between the individuals of any two species among the three are analyzed through the proposed method for the analysis on the correlation. Here, we must pay attention to the fact that the predominance in the hooked population-size of the yellow-fin tuna superficially raises the observed-values and the estimated ones in the correlation analysis falsely large enough as if to be able to give some significance upon the decoded facts, but, actually, not so high significance can be given to the results because of the poor catch of the big-eye tuna and the albacore. Accordingly, hardly any fact can be described on the correlation observable within a short range against its importance and interest.

12. At first, the expectant outline of the correlation to consider a row as a whole is forecasted from the distribution patterns of respective species in respective examples; next, the differences in the actually analyzed ones through the correlation analysis from the forecasted ones are examined example by example; then, the reasons causing these differences are discussed case by case, although not so much differences are found out.

13. It may well be concluded, as the summary of correlation of the hooked positions, that the tendency of occupying the same habitat is the strongest between the yellow-fin tuna and the big-eye tuna, that between the yellow-fin tuna and the albacore is a little weaker than this, and that between the big-eye tuna and the albacore is the weakest of all; and the aggregative relation is observable between the yellow-fin tuna and the big-eye tuna but the individuals of the albacore are inclined to be hooked rather repulsively against these two species. And these facts may be more or less relating to such differences in food habits and in body size as the yellow-fin tuna and the big-eye tuna commonly take zooplankton and small fishes and their sizes are not so different from each other against the fact that the albacore takes zooplankton and is a little smaller than the former two in size.

## Part Ⅱ Interval Analysis

14. The spacing analysis does not touch whether or not any of the inserted-hooks in the interval is occupied; and this makes it sometimes into confusion to translate the results of the analysis into the actually recorded structures. Accordingly, another analysis-method is deviced out, in which the length of the interval between the next individual is treated, *i.e.*, whether or not any of the inserted-hooks in the interval is occupied is taken into consideration. And this method is, for convenience' sake, called "the interval analysis".

15. At first, the constructing-process of the formulae applicable to the simplest condition is explained, in which the difference in the occupied-rate due to the difference in the fishing depths of the hooks caused by the slackness of the main-lines and that of the gradient of occupied-rate due to that of the soaking time are put out of consideration, for beneficial of understanding the way of thinking. Then, how to take the influence of each one of these factors into consideration is represented; and at last combining these two methods of modification, I have induced out the formulae, in which the influences of both factors are taken into consideration.

16. This method is effectively applied only to the examples in which considerably many individuals are hooked, because sum of the observed-values and that of the estimated ones in this method are no more than $(N-1)$. Therefore, the actual application is tried only to take the examples of the yellow-fin tuna, and I can not give any consideration to the difference in the decoded patterns with species, despite of its importance and necessity, because the smallness of the hooked population-size of other

species has much risk to introduce severe influence of accidental error into the decoded patterns.

17. I am obliged to compare the observed-values with the estimated ones in which the influence of only the difference in the occupied-rate due to that of the fishing depths of the hooks is taken into consideration, because I am afraid that the complicated exclusion-method of the influence of the gradient has much risk to introduce severe computation-error into the estimated-values, consequently into the decoding.

18. This method is thought to prove its merits only when this is used as a preliminary step to the next arrangement analysis; accordingly, no fact other than a short description on the characteristics of the deviation of the observed-values from the estimated ones is illustrated.

19. Then, the decoded pattern through this analysis-method is compared with that through the spacing one in which one hook-interval width is adopted as the unit-length of consideration, for the purpose of finding out what kinds of difference in the decoded structures are caused by the difference in the treatment of the inserted-hooks and what structures are suggested from these apparent differences in the decoded patterns.

20. The difference in the observed-value in the spacing analysis from that in the interval one represents the observed-value of the intervals of respective width in which one or more inserted-hook is occupied; and the difference in the estimated-value also represents the estimated number of such intervals. And the difference in the observed-value at $k_1$ from the estimated one in the spacing analysis represents the similar differences in the interval analysis in the range $0 \leqq k \leqq k_1$ cumulatively. Most of the apparent differences of the results of the spacing analysis from those of the interval ones can be explained from these reasons, while only a little can do so, and they are thought to represent some specific structures.

## Part Ⅲ Arrangement Analysis

21. The spacing analysis can tell us only the fact that how longly spaced pairs of individuals are more frequently observable than in the chance distribution, and the interval analysis can certify only the fact that how longly spaced individuals from the next ones are more frequently observable. But there remains another factor of importance untouched —— this is the manner of the arrangement of the intervals of respective widths.

22. It occurs naturally to our mind that there are some lots, each of which is constituted of some short intervals arranged successively, even if all the individuals are hooked by chance along a row; therefore, the method for estimating the expectant number of the lots, constituted of $W$ successively arranged intervals each of which is as long as or shorter than $k$ when all individuals are hooked by chance, is deviced out; and this method is, for convenience' sake, called the arrangement analysis.

23. Respective $k$, where the observed-values in the interval analysis exceed the estimated ones, are set to be the key-lengths to the analysis on the school-formation at respective steps, and the distribution patterns at respective steps in respective examples of the yellow-fin tuna are analyzed and the results are described in detail.

24. The results of the arrangement analysis are summarized as follows: population usually has the contagious schools of several folds and it is suggested as the structure of the highest order observable within a row that about a half of catch constitutes several schools of from 10 to 30 km in the projected widths and the average occupied-rate of the hooks in the part covered by these schools is estimated to be from several tenths to several times higher than that computed from throughout a row. But there are some examples showing some special structures. For examples, small population-size of the clusters at respective steps is one of the characteristics of the distribution pattern in Example Y 4, while large population-size is that in Example Y 7; weakly aggregative cluster-formation is that in Example Y 10, while narrow but dense cluster-formation is that in Example Y 12.

25. The results of the arrangement analysis can tell us the numbers of the clusters of respective population-size, in contrast with the fact that the spacing analysis can simply tell us the probable distance among the centers of the schools —— secondarily, the total number of the schools regardless of their population-size is estimative. Moreover, it is far easier to translate the facts guessed out from the arrangement analysis into the projected distribution pattern recorded actually than to translate the facts guessed out from the spacing one into it; and also when we refer to the results of analysis together with the projected distribution pattern recorded actually, far more detailed facts are deducible from the arrangement analysis than from the spacing one, —— for example, the numbers of the schools of respective population-size, their probable positions, widths *etc.*, consequently occupied-rate *etc.*, of course including the distances among their centers.

In addition to these merits, it is one of the most powerful merits of adopting the arrangement analysis that the individuals forming respective aggregations pointed out through the arrangement analysis theoretically have a definite proof supporting that these individuals are hooked aggregatively, in contrast with the fact that the observed-value at a certain $k$ in the spacing analysis exceeds largely the theoretical one, strictly speaking, does not necessarily mean or has no proof supporting that each one of the individuals from respective pairs is hooked aggregatively.

26. The structure at the highest order observable within a row decoded through the arrangement analysis is compared with that through the spacing one, example by example. But generally speaking, no serious difference between the decoded patterns through these two different analysis-methods can be found out in most of the examples in which clear school-formation is suspected; but only a little differences are found out in the examples in which no clear school-formation is suspected and these differences are thought to be due to the fact that the pattern decoded through the spacing analysis and that through the arrangement one in such an example reveal the pattern

to see from quite the different point of view because of the most fatal demerit of the spacing analysis pointed out in paragraph 25.

27. The practically applicable method, in which the influence of the presence of the buoy-lines on the arrangement analysis is excluded, has not yet established; but two tracks of the trials for the exclusion are shown.

28. In the last section of this report, the distribution patterns of some commonly observable pelagic-fishes —— the anchovy, the sardine, the horse mackerel, the mackerel, the yellowtail, the salmons, the skipjacks, the albacore, the yellow-fin tuna, the big-eye tuna and the marlins and the spear fishes——in relation to their food habits, the distribution of their prey, that of their predators, their size, their swimming ability, the fishing methods by which they are caught, are discussed, for the purpose of finding out some suggestions upon the reasons why the tunas and the salmons do not form any school other than considerably dispersed one in their usual habitats and such a pattern may bring what profits and what obstacles to survive well. And as the general tendency, it is found that the denser school is observable, when (1) the denser their prey are distributed, (2) the severer the variability of the density of their prey is, (3) the severer they are attacked by any other animal, (4) the more dishomogeneous the environmental conditions in their habitats are, and (5) the smaller their size is, consequently the weaker their swimming ability is. And also some relations can be suggested between the schooling-tendency and the fishing-methods. And deducing from these facts, I want to conclude that the dispersed structures of the salmons and the tunas are acceptable and many profits and scarcely any obstacle are thought to be introduced to do so.

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# 二艘曳機船底曳網の模型実験—I※

谷　口　武　夫

## Model Experiments on the Japanese Two-Boat-Type Trawl Net I※

By

Takeo TANIGUCHI

The working behaviours of the Japanese two-boat-type trawl net operating in the East China Sea and the Yellow Sea were studied through a series of model experiments based on TAUTI's law of comparison of fishing net (Figs. 1 & 2). The shape and the towing resistance of the net were observed in relation to the horizontal spread at the frontal ends of the wings, the towing speed, the arrangement of the floats, and others.

Results obtained are as follows:-

1) When the distance between two spreaders attaching to each frontal end of the wing is smaller than 30 m, the horizontal opening at the net-mouth increases considerably with these distance, while vertical one decreases with it. But when the distance between spreaders becomes greater than 30 m, the horizontal opening as well as vertical one is almost invariable, regardless of the distance between the spreaders (Plate 1 & Fig. 3).

The towing resistance increases markedly with the distance between the spreaders, and the rate of increase in the resistance of the net is, when the distance between the spreaders is wider than about 30 m, greater than when it is narrower (Fig. 4).

2) When the towing speed is lower than about 2 mile/hour, the vertical opening at the net-mouth decreases gradually with the increase in the towing speed. But when the speed becomes higher, the vertical opening at the net-mouth is almost constant, regardless of the speed. The horizontal opening at the net-mouth is always constant, too (Plate 2, Figs. 5, 7 & 8).

The towing resistance increases nearly in proportion to the square of the speed (Fig. 6).

3) The variation of the buoyancy, within a certain limit, of the float attaching to the net-mouth and its neighbourhood makes little change in the vertical opening of

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the mouth, so far as the towing speed is not smaller than 2～3 mile/hour. But, however much the buoyancy may increase by some measure, it brings about the floating up of the net without increasing the vertical opening at the net-mouth (Figs. 9, 10 & 11).

4) The opening at the net-mouth solely depends upon the construction of the net. Namely, to decrease the force given on the head rope attaching to the net, to increase the length of the spreaders of frontal end of wings, or to arrange the fit netting in each part of the net is fundamentaly of some use for the increase of the opening at the net-mouth.

But when we want to get a good result, we should employ all these three, or at least two, of the methods together, otherwise we may scarcely expect any good effect.

## 緒　　言

近時底曳網資源の涸渇と，魚探器の発達およびその普及に伴ない魚群の分布状況が判明するにつれ，現行漁具の網口をできるだけ高揚し，更に上層水域の魚族をもあわせ漁獲しようとの試みは全底曳網業界の焦眉の課題とされていた。爾来これに関する研究はすこぶる盛んで，二艘曳機船底曳網については，研究当初（4～5年前）在来のものの網口の高さは，これまでなされた多くの報告及び本報でも詳述するように2～2.5 m 程度であった。その後，著者等のこれに関する一連の研究が進むにつれ，在来のものの2倍（5 m 前後）迄（これにより以西漁場ではここ数年間引き続いて，エビ漁等に多大の成果がおさめられた），続いてごく最近では10 m 前後の，在来のものに較べて実に4倍までに網口を高めることも実証出来，近く各業界でも実用化される段階に至っている。

これらについての詳細は後日順を追って報告するが，本報ではまず在来の漁具が流水中で如何なる性能をもっていたか，或いはその如何なる点を改良すれば前述の目的が達成できるか等を推知する予備試験として，従来以西漁場で使用されていた代表的底曳網（Figs. 1 & 2）の模型を作製し，特に網口付近の網高さを高めるという観点からその各種要因について水槽実験により検討した結果を報告する。

## 実験並びに模型網

網口の高さに影響する要因としては，既報の多くの実験でも指摘されているように，漁具の操作上からいえば両船間隔（両手木間隔）と曳網速度，設計上からは浮子或いは抵抗板（カイト類）等による浮揚力，ヘッド・ロープとグランド・ロープにかかる張力比及び手木の長さの問題，更には網の構造そのものの違い等種々の要因が考えられる。

実験はこれらの諸要因が網成，特に網口の高さにどのように影響するかについて，本所備付けの流水水槽（測定部の大きさ：長さ2 m，巾1.35 m，深さ0.9 m）で，昭和32年7月から8月にかけて行なわれたものでる。

観測は網成りについては総て写真撮影，流速は広川式電音流速計（感度5 cm/sec），抵抗値の測定は特製の桿秤（感度1 g）を工夫して行なわれた。

なお供試模型網は田内の相似則[1]に従い次のように作製された。

a）模型網の寸法 $\lambda'$ と実物網のそれ $\lambda''$ との比は $^1/_{50}$ とした。

b）網地は実物網のそれがタール染マニラトワイン（比重 $\rho''=1.34$）であるのに対し模型網にはナイロン

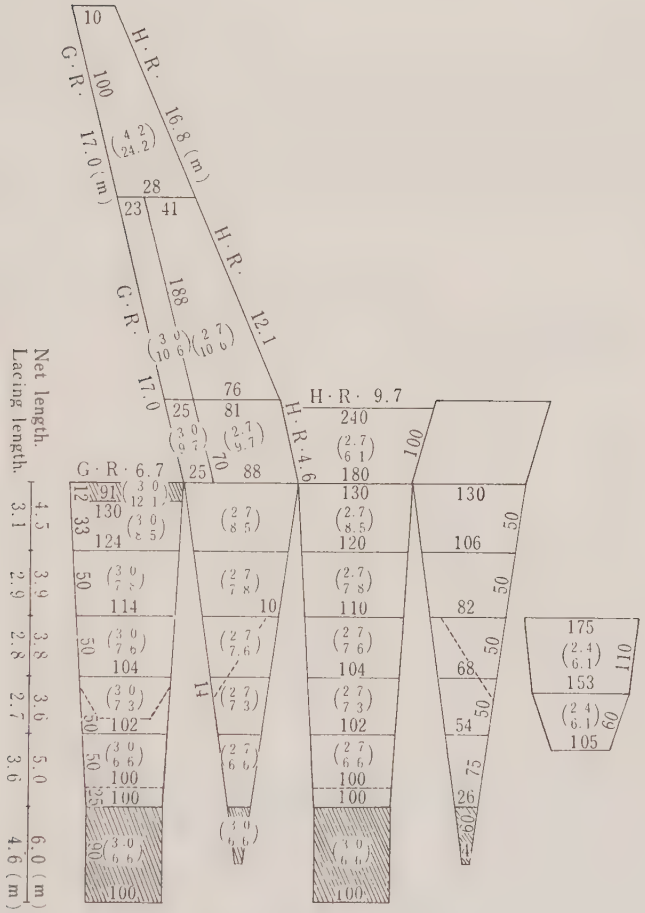



Fig. 1. Gear construction of the Japanese two-boat-type trawl net.

Note : Upper and lower numerals enclosed in brackets indicate diameters of netting twine in *mm* and mesh size in *cm*, respectively. Other ones, which are not enclosed in bracket and lacking symbols, show mesh number. Moreover, the parts of oblique lines signify the double cord mesh.

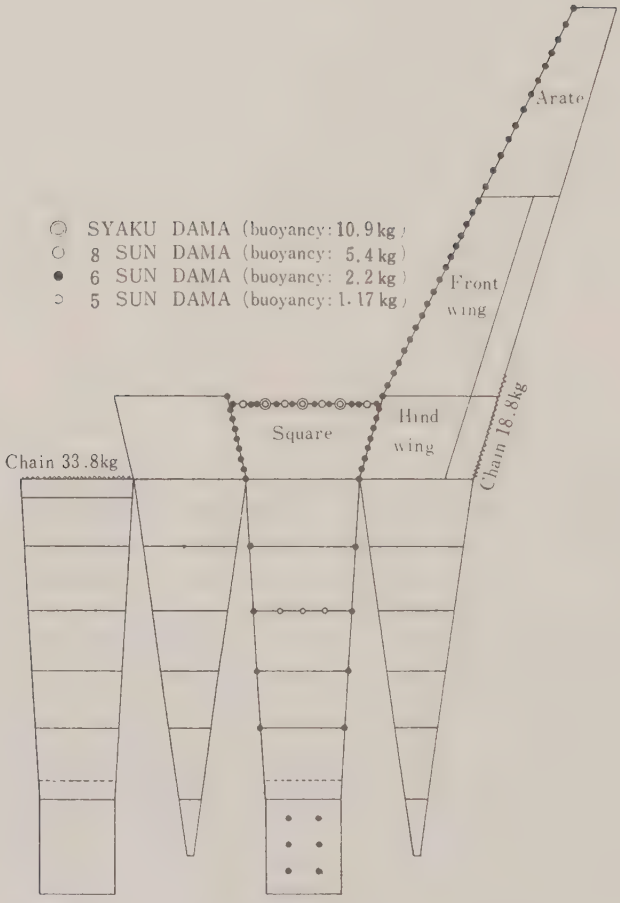



Fig. 2. Standard arrangement of floats and chains.

糸（$\rho'=1.13$）を用い，模型の目合 $L'$ と糸の太さ $D'$ とは実物網のそれら $L''$，$D''$ に対して相対応するどの部分でも $L'/L''=D'/D''=0.121$ とした。

c）このように作られた模型と実物網の流速比 $v'/v''$ は $0.225$ となる。

d）綱類については，ヘッド・ロープ 及び マン・ロープ（$\rho''=5.0$），袖付部 グランド・ロープ（$\rho''=1.30$）水戸口付部グランド・ロープ（$\rho''=1.26$）に対して模型ではすべてテビロン糸（$\rho',=1.40$）を用い，抵抗を見掛上の重さに比較し無視して，綱の太さは模型のそれ $D'$，と実物網のそれ $D''$，との比をヘッド・ロープ及びマン・ロープに対しては $0.101$，袖付部グランド・ロープには $0.0263$ と，水戸口付グランド・ロープには $0.0242$ とした。

e）浮子については抵抗を無視し，模型と実物網の相対応する部分の浮力を $F'$，$F''$ とすると $F'/F''$ は $4.36\times10^5$ となる。なお模型及び実物網の抵抗及び沈降力を夫々 $R'$，$R''$ 及び $W'$，$W''$ とするとその比もこれに従う。

## 実験結果とその検討

### 1）両手木間隔の広狭と網成り及び流水抵抗変化

これについては既に断片的な結果ではあるが野村の模型実験[6]，並びに葉室[7][8][9]の実物網についての詳細な報告がある。

葉室[7]はそこで，曳船間隔の広狭により網口の高さは夫々低くまた高くなり同量の間隔の拡大（減少）では狭い曳船間隔からの拡大の方が広い所での拡大の場合より網口の高さの減少率は大きい。また曳船間隔が拡大されると手木間隔も大きくなるが，その手木間隔の拡大率は両船間隔が拡大する程逓減する。そして網成り及び網具にかかる抵抗等から総合的に考えると曳船間隔としては，350 m 前後が最適であることを指摘している。

この網については，曳網速度約2.5ノットで両手木間隔を4～40 m 前後に変えた場合の網成り及び網口周辺の拡網状況を観測した結果を夫々 Pl. 1 及び Fig. 3 に示した。Fig. 3 で二重丸は網口の高さ（天井

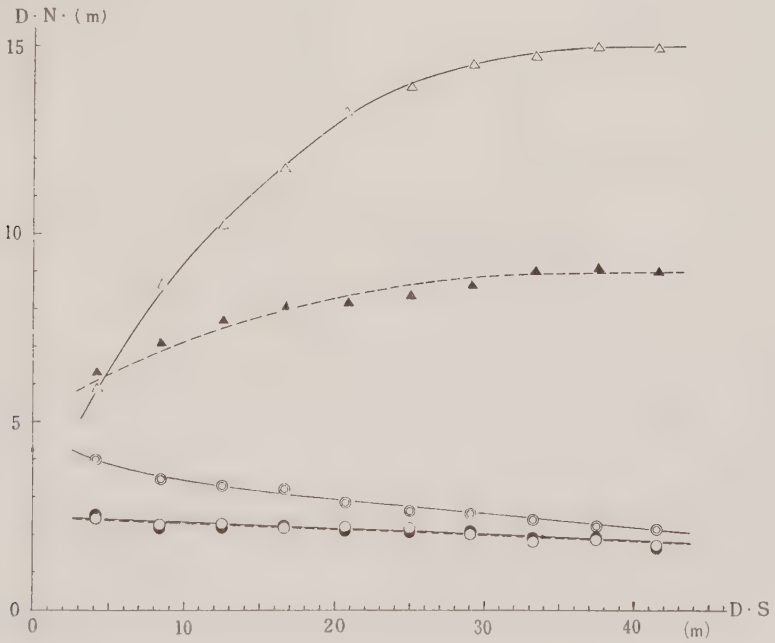



Fig. 3. Deformations of the net-mouth [*D. N.*] at various distance between two spreaders attaching each frontal ends of the wings [*D. S*] under 2.5 mile/hour towing speed.
Abbreviation, ◎ : the heights at the middle of frontal edge the square part, ○ & △ : the height and horizontal spread at the frontal ends of the hind wings, ● & ▲ : the vertical and horizontal dimention of the cross section of the net at the frontal edge of its bag-net.

網中央先端の網底からの高さ），白丸及び白三角は口脇，即ち先，奥両袖の縫合部における両袖の網立ち及び水平的な拡がりを，黒丸及び黒三角は嚢口，即ち天井網後端と嚢網前端との縫合部における高さ及び水平方向への拡がりを示す。また同じく流水抵抗の変化については Fig. 4 に示した。

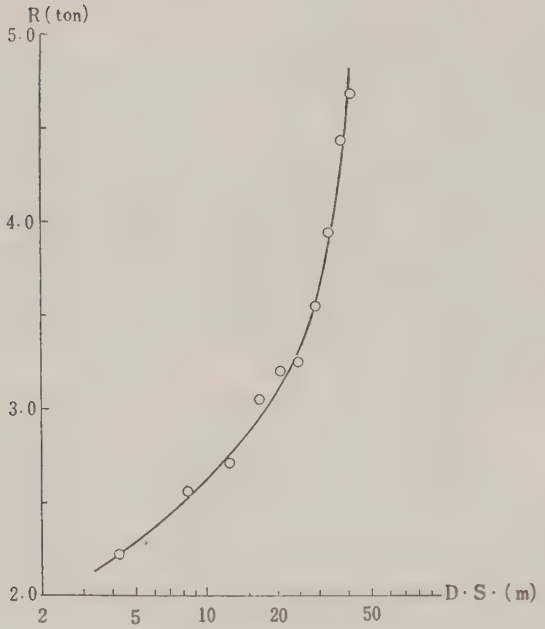



Fig. 4. Relationship between the resistance〔$R$〕and the distance between spreaders of the frontal ends of the wings〔$D.\ S$〕under 2.5 mile/hour towing speed.

これらの結果は上述の葉室の場合とよく符合し（測定値については両者の網具が同一のものでなくまた測定条件も異なるので比較するのは無理であるが，共に比較的近い値を示している），両手木間隔を拡大するにつれ網口は横方向へは急激に拡がるのに対し高さは除々ではあるが減少する。また嚢口は手木間隔にかかわりなく常にほぼ定状をなしている。

次に網具にかかる流水抵抗はその拡がりと共に急激に増加することもまた前述のそれと同様であるが，この実験から追加されることとして，手木間隔が 30 m 附近を境にそれより狭い範囲で間隔を拡大した場合の抵抗増加率と広い範囲でそれを拡大した場合の増加率はやや異り，後者が前者より大きくなっていることである。このことは Pl. 1 及び Fig. 3 の手木間隔による網成り変化の関係からも容易に推察することができる。

一般に手木間隔（両船間隔）の決定は，その目的とする魚群の動静により網口の高さを問題とすべきか或いはその平面的な拡がりを大きくすべきか等により一概にいうことはできないが，あまり狭くても網成りが不安定で，感心できず，また開き過ぎても前述の如く手木間隔を拡げた割に網口の横方向の拡がりは期待できず，いたずらにそれは“尾はね現象”をはげしくするだけで全体的な網成りも不自然である。したがって網具自体を総合的に判断するなればどの網でも前述の葉室の指摘と同様に手木間隔としては 30～35 m（この数値を葉室の実験結果[9]から両船間隔に換算すると 300～350 m と推定される）で，操業されるのが理想であると考えられる。

### 2）曳網速度変化による網成り及び抵抗

このことについても既に佐藤[2]，宮本[3]，猿用[5]，野村[6]等の模型網についての結果，更に葉室[7][8][9]の

実物網についてのもの等数多くの報告がなされている。これらの結果によれば，網口の高さは曳網速度2～3ノットまでは速度の増加と共に急激に低下，2～3ノット付近からその低下は次第に少なくなり或る一定の高さに落着き（2～2.5 m），抵抗値も曳網速度が1.5ノット前後より速い範囲では速度の自乗もしくはこれよりやや小さい値に比例することが明らかにされている。

しかしこの網ではどうであるか，このことについては更に深く知る必要もあったので，前項の結果から考えて手木間隔33.2 mのものを主眼に，更に24.9，及び41.5 mの場合のものについても網成り並びに抵抗についてそれぞれ観測した。

結果はPl. 2, Fig. 5（図中の記号はFig. 3に同じ），及びFig. 6に示したとおりで，上述の各種実験結果と同様，網口付近の横方向の拡がりはほとんど変らないが高さは速度の増加と共に急激に低下し2ノット前後からほぼ一定の高さ（網口中央の高さでは静止時のそれの約半分の2.5 m）に落ちついた。抵抗についても本実験の範囲（1～4ノット）内では前述の結果と大差なく速度の自乗にほぼ比例することがみられた。

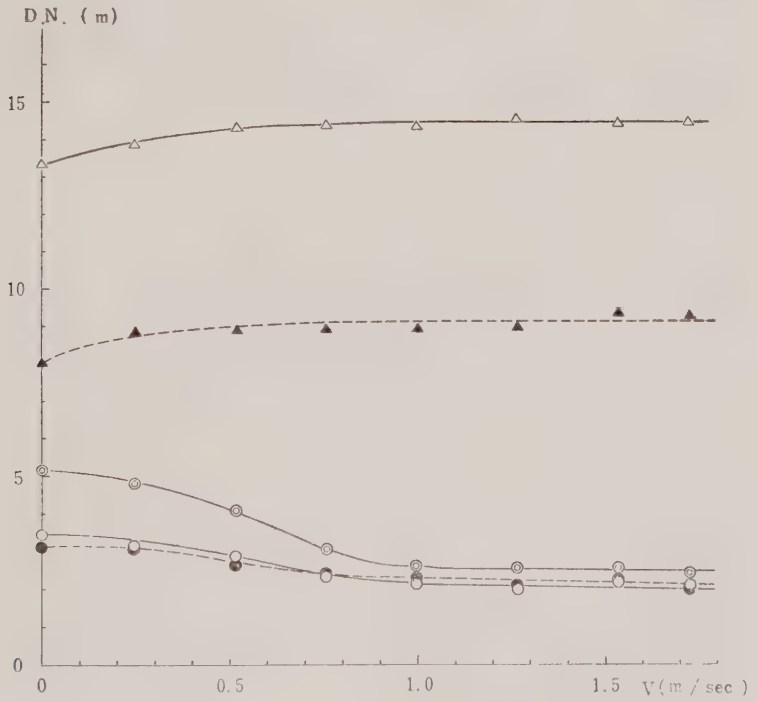



Fig. 5. Deformation of the net-mouth [*D. N.*] at various towing velocity [V] under 33.2 m in distance between spreaders of the frontal ends of the wings.
Note : Symbols are the same as Fig. 3.

Fig. 7は手木間隔を24.9，33.2及び41.5 mの3通りにとった時の曳網速度と網口の拡がりの関係を比較したものである。図中黒四角及び白四角はそれぞれ手木間隔24.9 mの場合の網口中央の高さ及び横方向の拡がりを，黒丸及び白丸は同様にそれぞれ33.2 mのときの，黒三角及び白三角はそれぞれ41.5 mのときのそれを示す。

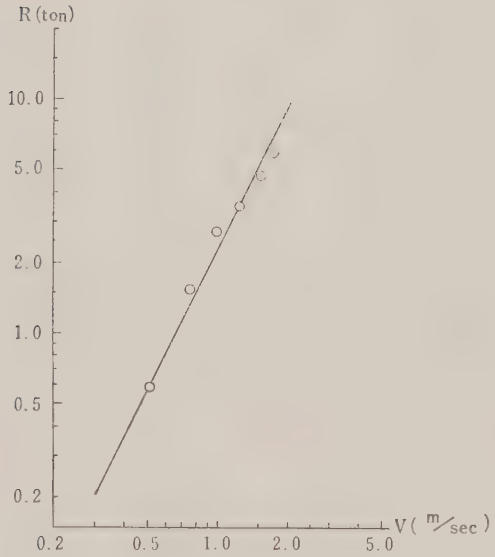



Fig. 6. Relationship between the resistance [$R$] and the towing velocity [$V$] under 33.2 m in distance between spreaders of the frontal ends of the wings.

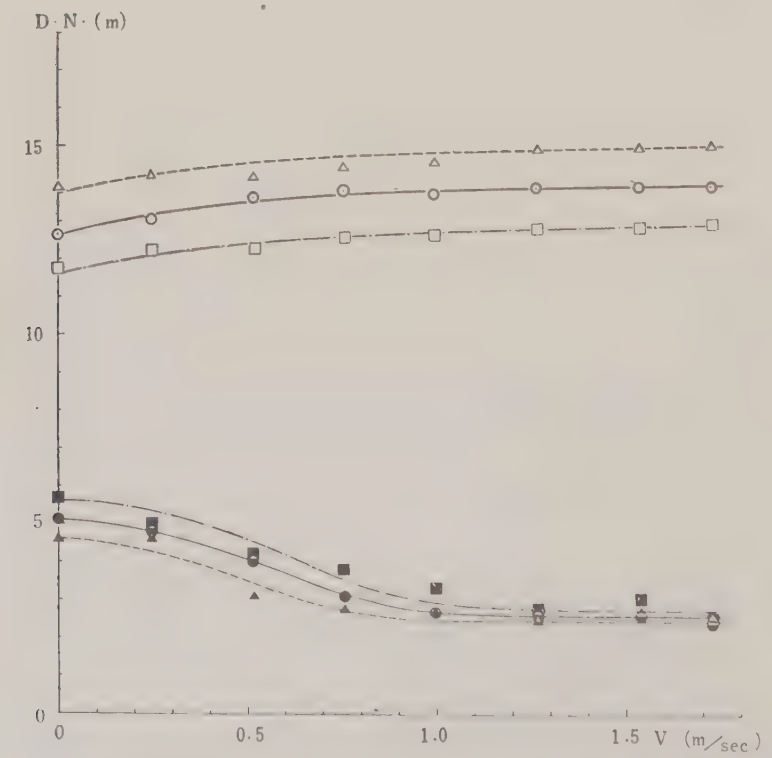



Fig. 7. Comparison of the deformation of the vertical (filled marks) and horizontal opening (open marks) of the net-mouth, the distance between spreaders of the frontal ends of the wings of which is as long as 24.9 m (square), with those of the net the distance between spreader of frontal ends of the wings of which is choosed 33.2 m (circle) or 41.5 m (triangle).

これから曳網速度が2ノットより小さい範囲では網口の高さは速度，手木間隔の双方の影響を受けて大きく差を生じるが，2ノットより大きくなるといずれの影響をもほとんど受けない。換言すると両手木間隔，曳網速度等の操作で網口の高さを高めまたは低めることのできるのは曳網速度が比較的小さい場合だけで，速度が大きくなり2ノット前後より大きい範囲ではそれはほとんど効果なく，網口の高さはこれら漁具の操作上の要因以外の他の要因により既に定まっているものと推測される。なお襞口の拡がりは，手木間隔，速度等いずれの要因にもかかわりなく常にほぼ定状をなしていることが観察された。

猿田[5]は速度が大きくなると天井網に皺を生じ，この部分が後方に折り曲って網成りはきわめて不良になることを指摘している。Fig. 8は各速度における天井網の変化を図示したものであるが，この場合もやはり速度の増加と共に天井網の曲折がひどくなり，この部が垂れ下って実質上の網口の高さは減少されるなどいちぢるしく網具の性能は削減されると思われる。この天井網の曲折或いは垂下によっておこる実質的な網口の高さは見掛上の網口の高さ（天井中央前端の高さ）に較べて，曳網速度1ノットで4，2ノットで3.5，

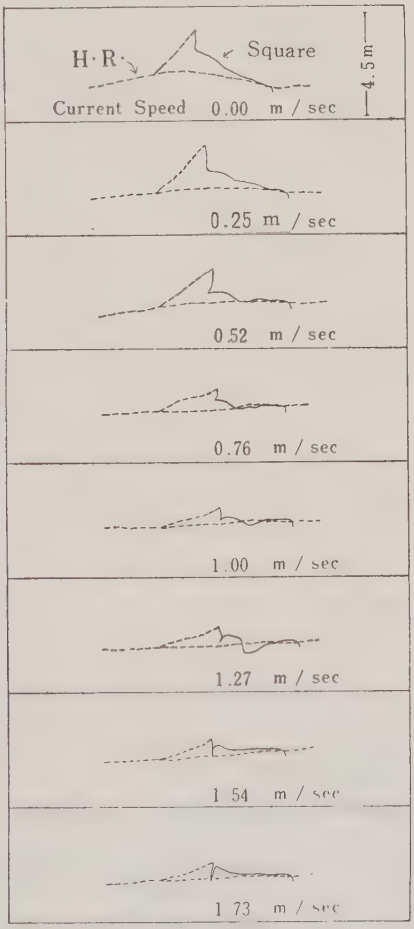



Fig. 8. Longitudinal section of the net-mouth and its neighbourhood with special reference to square part, at various towing velocity and under 33.2 m in distance between spreaders of the frontal ends of the wings.

3ノットでは2.5割近くそれぞれ低くなっていた。

この原因は主として囊口の大きさに比し天井前部の長さが長過ぎることによるもので，適当にそれを短かくすればこの現像は解消することができるが，網口そのものの高さは低下する（これについての詳細は続報で述べる）。

以上網口を高くする点からは曳網速度はおそいにこしたことはないが，きわめておそくしなければたいした効果もあがらず，むしろこのような網具の場合は総合的な網成りその他目的物の見地から先に棄室等の指摘にもあるように，2.5ノット前後の曳網速度が最も当を得たものであると考えられる。

### 3）浮子の浮揚力と網成り変化

従来，底曳網の網成りを整え，或いは網立ちをよくする等で，漁獲能率を上げるには一にそれに対する浮子の配置或いはその浮揚力の調整如何にあると考えられ，現場当事者はもっぱらその一着一除に腐心していたのが現状であった。このため浮子についての研究が重要視され，現行浮子の特性或いはその改良等について，小林[10]，小山[13]，谷口[11][12]，高山[14][15]等多数の実験がなされた。

はたして上述のごとく曳網中の漁具の網成り，特に網口附近の網立ちに浮子の効果があるものかどうか，曳網速度2.5ノット，両手木間隔 33.2 m のもとで，天井網前端，先及び奥袖等網口附近の網立ちに関係が深いと考えられる部分の浮子の浮揚力或いはその配置をいろいろと変えその時の網成り状況を観測した。

Fig. 9は天井網前部の浮揚力を変えたときの口脇，網口及び囊口の高さ（図中の記号は Fig. 3 に同じ）

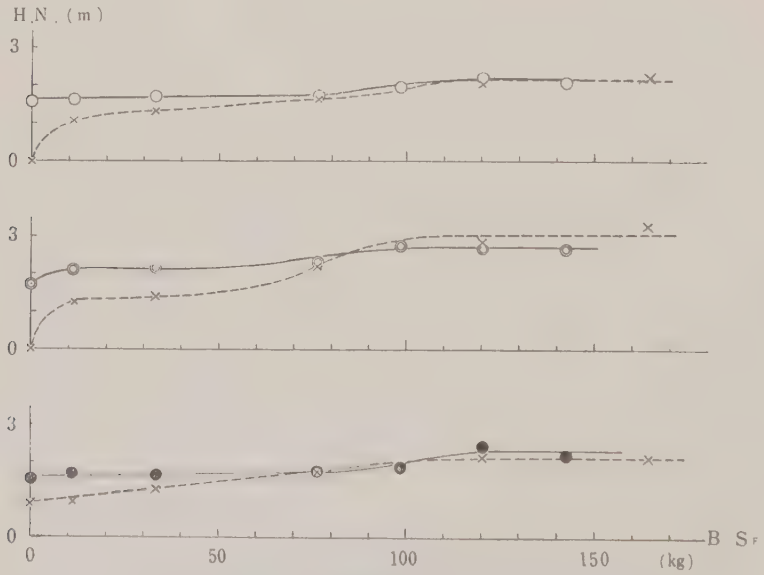



Fig. 9. Heights (the vertical opening) of the net-mouth 〔$H.N.$〕 at various buoyancys of the float attaching to frontal head rope of square 〔$B.S_F$〕 under 2.5 mile/hour towing speed and 33.2 m in distance between spreaders of the frontal ends of the wings.

Note : Real-lines indicate 〔$H.N.$〕 at 〔$B.S_F$〕 in which the arrangement of floats and chains of the other parts are kept in standard (Fig. 2 & Table 1–A). Broken-lines show 〔$H.N.$〕 in the same conditions as to the above excepting all floats attaching to the front wings and hind are removed (Table 1–B). Symbols are the same as Fig. 3.

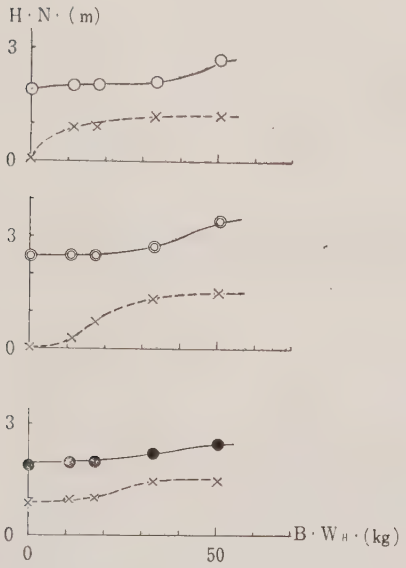



Fig. 10. Heights of the net-mouth [$H.\ N.$] at various buoyancys of floats attaching to hind wing [$B.W_H$] under 2.5 mile/hour towing speed and 33.2 m in distance between spreaders of the frontal ends of the wings.

Note : Real-lines indicate [$H.\ N.$] at [$B.\ W_H$] in which the arrangement of floats and chains of the other parts are kept in standard (Fig. 2 & Table 2–A). Broken-lines show [$H.N.$] in the same condition as to the above excepting all floats attaching to square and front wing are removed (Table 2－B). Symbols are the same as Fig. 3.

を示したもので，実線は天井前端部以外の浮子の配置はこれまでどおり（Table 1－A），破線はこれらを全部取り除いた場合（Table 1－B）の結果を示す。同様に Fig. 10 及び Fig. 11 はそれぞれ奥袖部（Table 2－A，Table 2－B），先袖部（Table 3－A，Table 3－B）の浮揚力を変化させた場合のものである。

結果は予期に反し，ほとんど浮子の効果は認められなかった。これは葉室[9]の結果から推測されるようにヘッド・ロープにかかる張力がきわめて大きく（0.7 t 前後）各部にかかる浮子の浮揚力はまったく問題にならないためであろう。しかしその浮揚力を網の各部に適当に配置することによっては或る程度の効果がみられる。即ち各部に与えられた浮揚力は単にその部位の網立ちに関係するだけでなく各部に与えられたものが互に関連し合ってその効果を現わす。換言すると特定部位，例えば網口を高める場合には，その部の浮揚力を単に増大させるだけでなく，それにともなって他の口脇附近の浮揚力をも同時に減少させなければならないということである。この結果は局部に片寄った力がかかることになり全体的な網成りも良好とはいえず，漁獲性能上からも決して得策とは考えられない。なお荒手部及び襲の後部等に装着された浮子の効力は，その部の立網には役立つが網口附近まではその影響を及ぼすことはないと認められた。

しかるに先に佐藤[2]は特殊抵抗板（カイト），葉室[8]は特殊フロートをそれぞれ使用して網口の高さを従来のものより倍近く高めることができたと報告している。しかしこれらの結果は，いずれも浮揚力とは別に網具の構造自体にも工夫改訂を加えた場合であり，（前者では天井と袖網との間に三角網を挿入し，網口を抵抗板の揚力で強制的に引きあげても支障がないよう，天井前端に充分余裕をとってあり，後者でもヘッド・ロープ及びグランド・ロープの長さを変え，それにかかる張力比の割合を適当に調整した。）浮揚力の増

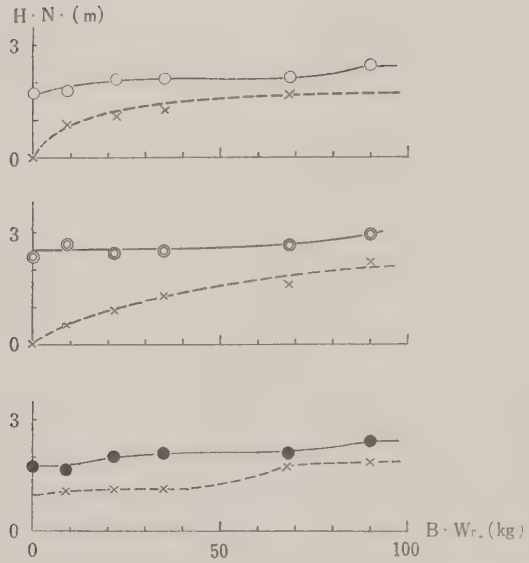



Fig. 11. Height of the net-mouth〔H.N.〕at various buoyancys of floats attaching to front wing 〔$B.\ W_F$〕under 2.5 mile/hour towing speed and 33.2 m in distance between spreaders of the frontal ends of the wings.

Note : Real-lines indicate 〔$H.\ N.$〕at 〔$B.\ W_F$〕in which the arrangement of floats and chains of the other parts are kept in standard (Fig. 2 & Table 3－A). Broken lines show 〔$H.N.$〕in the same condition as to the above excepting all floats attaching to square and hind wing are removed (Table 3－B). Symbols are the same as Fig. 3.

Table 1. Arrangement of floats attaching to the net

| Part | A | B |
|---|---|---|
| Frontal Head Rope of Square | Buoyancys : 0～141.7 Kg | Buoy. : 0～163.5 Kg |
| H. R. of Hind Wing | Buoy. (one side) : 17.6 Kg ( 6 Sun Dama : 8 ) | none |
| H. R. of Front Wing | Buoy. (one side) : 35.2 Kg ( 6 Sun Dama : 16) | none |
| H. R. of *Arate* ; Buoy. (one side) : 30.4 Kg ( 6 Sun Dama : 14), Bag Net ; Buoy. : 34.3 Kg ( 6 Sun Dama : 14, 5 Sun Dama : 3 ) | | |

Table 2. Arrangement of floats attaching to the net

| Part | A | B |
|---|---|---|
| H. R. of Hind Wing | Buoy. (one side) : 0～50.3 Kg | Buoy. : 0～50.3 Kg |
| H. R. of Front Wing | Buoy. (one side) 35.2 Kg ( 6 Sun Dama : 16) | none |
| Frontal H. R. of Square | Buoy. : 76.3 Kg (Syaku Dama : 3, 8 Sun Dama : 2, 6 Sun Dama : 12) | none |
| H. R. of *Arate* ; Buoy. (one side) : 30.4 Kg, Bag Net ; Buoy. ; 34.3 Kg | | |

Table 3. Arrangement of floats attaching to the net

| Part | A | B |
|---|---|---|
| H. R. of Front Wing | Buoy. (one side) : 0～90.7 Kg | Buoy. : 0～90.7 Kg |
| Frontal H. R. of Square | Buoy. : 76.3 Kg (Syaku Dama : 3, 8 Sun Dama : 2, 6 Sun Dama : 12) | none |
| H. R. of Hind Wing | Buoy. (one side) 17.6 Kg (6 Sun Dama : 8) | none |
| H. R. of *Arate* ; Buoy (one side) : 30.4 Kg, Bag Net ; Buoy. : 34.3 Kg | | |

大もさることながら，それよりはむしろヘッド・ロープ（主として天井前部）にかかる張力の軽減に帰因したものと推察される。

本実験の結果では或る数以上の浮揚力の増大はいたづらに網具全体を海底から浮きあがらせる効果があるだけで網口の高さは或る一定値以上はほとんど高まらず，網具そのものによって構成上既に定まっているものと考えられる。

また，葉室[8]は浮子をまったく装着しない裸網でも，その網高さは絶対零ではなく相当量ある（網口で約0.6 m 前後）ことを報告しているが，本実験の場合では，荒手，先袖，嚢口等局所的には或る程度の網立ちがみられたが，天井前部が底面に吹きつけられて網口の高さは零であった。これらの相違は前述のごとく両者の網具の構造上の違いに原因すると考えられる。

以上総合的に見ると，網具の構造次第によっては浮子の効果も無視できないが，在来の網具のごとくヘッド・ロープに相当大きい張力がかかっているものでは浮子の数を増してもほとんどその効果はなく，いわんやあより実用的でないカイト，或いは特殊フロート等は無用の長物であり，この際浮子の効用は投網直後の網成りを整えるだけのものとして，むしろ現状よりこれを減じ網具にかかる無駄な抵抗を少しでも減少させることに留意する方が得策と考えられる。

**4）網具の構成に関する二，三の要因と網成りについて**

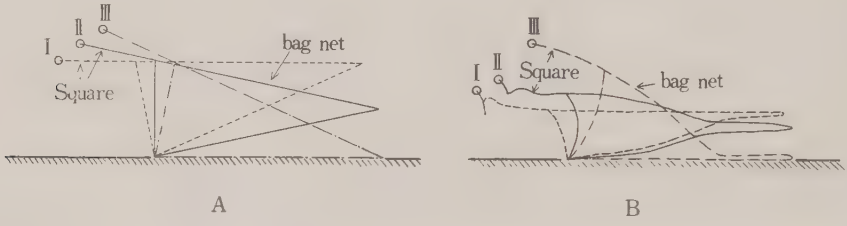
**ヘツド・ロープとグランドロープにかかる張力比と網成り**　従来使用されていた底曳網の設計図を比較対称すると，以前に使用されていたもの程ヘッド・ロープの長さはグランド・ロープのそれより長いが，年と共にそれは縮められ，最近では逆にグランド・ロープよりは短く使用されるような傾向が認められる。これは前者の場合は下網特に水戸口部が海底の砂泥中に喰込むので，船の曳網負荷が増大し，また下網の海底との摩擦よにる網地の摩耗損傷がはなはだしかったので，これを防ぐために後者のように改められてきたものである。

実験によるとヘッド・ロープとグランド・ロープにかかる張力比の違いは漁具の網成りに大いに影響を及ぼし，その比が大きく，或いは小さくなるにつれて網口附近の網立ちはそれぞれ相当低下，或いは高くなる（これについてはトロール網の模型実験* で詳述する）。従って前述の場合では後者は前者よりヘッド・ロープとグランド・ロープの張力比が大きくなるよう改めたことになり網口を高めるという観点からは逆効果で，網口の高さは前者に比し低くなっていると考えられる。

葉室[8]はヘッド・ロープの長さとグランド・ロープのそれを適当に調整することにより浮子としては普通の硝子玉だけを用いても，従来のものより網口の高さを２倍近く高くすることができたと報告している。

本実験でもこのことは確認済みであるが，このことだけでは，なるほど天井中央前端の高さは２倍近くの高さになるが，網口がやや後方に傾斜し天井網から嚢網前部の上網が斜め後方に大きく吹かれて彎曲しフラッパー附近で極端にくびれて（天井後端と嚢の前端の縫合部にロープを入れ縮結を入れるとそこでもくびれる）それ以後の嚢部は偏平になりその調整をちよっとあやまると Fig. 8 で示したように網口の実質的な高

さはほとんど変らず，ただ天井前端部のみが曲折して極端にあがるだけで網成り上からも決して良好とはいえず，嚢部は底面に強く圧下される。




A　　B

Fig. 12. Schematic representations of the longitudinal section of the square and the bag-net part.
Note : A represents the schema in which only the geometrical elements are taken into consideration, while B does the hydrodynamical ones.

Fig. 12 は以上のことがらを模式的に図示したもので，A図はそれぞれヘッド・ロープの長さがグランド・ロープのそれより短い場合（Ⅰ），両者相等しい場合（Ⅱ），逆に長くした場合（Ⅲ）の天井及び嚢網の断面の幾何学的な比較，B図は同じくこれに流体力学的な条件を加味した場合の関係を示したもので，その間の事情をよく推察することができる。

以上ヘッド・ロープの長さをグランド・ロープのそれより長め，それにかかる張力を減少するようにすれば，ヘッド・ロープに装着された浮子の効率も増大し，加うるに網口そのものの形がやや仰向き加減にあることから上網部が潮を受けて吹き上げられること等と相俟って網口の高さは相当高くなるが理想的な拡網とはいえず，ヘッド・ロープの長さとグランド・ロープの長さとはむしろ等しくして網成りを整え，両者の張力比の減少には別の工夫をこらし，それにより網口の高さを上げるようにするべきである。

**手木の長さと網成り**　野村[6]によれば天井網の高さの減少率はその点における袖網の水平方向となす角 $\theta$ に関係し，$\theta$ が小さい程その減少率は小さくなる。

これの実用化として従来の網具の設計者はややもすると口脇の奥袖の網巾を必要以上に広くとり，或いはまた天井網と袖網との間に三角網等を挿入し極端に網口を拡げたものにしてこと足りるかの如く考えがちであった。

これらはいずれも網具の静止状態を念頭においたもので，曳網時における網成りを認識していないことより生じた誤謬である。即ち前者の設計ではいたずらに袖網の外側の彎曲をひどくして網口の横方向の拡がりを増すだけで高さは一向に高まらず，後者の場合でも，（これについては野村の実験[6]があり網口の高さは従来のものとほとんど変りがないことが報告されている）挿入された三角網は単に天井網の前端の長さを長め或いは前者のごとく袖網の巾を必要以上に広めるだけで，換言すると天井網の曲折，或いは網口の横の拡がりを増大させるだけで実質的な高さは高まらない。即ち曳網中ではこれらは前述の $\theta$ を減少するということにはならず，基本的には袖端の手木の長さにより網口高さが決定されているものと思われる。従って他の諸要因の適切なる調整を工夫せずして単に使用網地を添加するだけでは何等意義なく，却って抵抗の増加，網成りの異常を助長させる原因になるだけであるといえる。

手木の長さは現行では 0.8～1 m 前後であるが，もし今後実際の操業においてその長さを相当長めても網具の操作その他の点で何ら支障が感じられないとするなれば，その長さが長ければ長いもの程袖部は勿論のこと，網口の高さも高くなることが実験により確かめられた。（これについてもトロール網の模型実験* で詳述する。）

**網地の配備と網成り**　巣室[9]は曳網中の網各部の高さは，浮子その他の外力等で強制的に揚力を網に与

えることよりは，むしろ構成された網地自体の流体抵抗による，従って網成りの良否は基本的に網地の抵抗の適正な配分構成によって決まると指摘し，天井及び嚢の上網の各部に適正な揚力が増すように，また嚢の側網地は網口から入り込んだ流水のはけ口とするよう適当な網地を配備することで或る程度網成りをよくすることができたと述べている。

このことについては既に現場当事者の間でも従来から関心が持たれ，網糸の材料上からは上網部に極力比重が軽く，糸表面の粗雑なもの，下網部の網地にはその反対の性質のものを撰択する等，また網地としても上網に流体抵抗の大きなものを配する等（極端な場合は天井前部にキャンバスを取り付けられたこともある）種々網口を高める工夫がなされてきた。

しかし，これらは Pl. 2からも判るように，静止時もしくは曳網速度が極めておそい場合には効果もあると考えられるが，曳網速度が2.5ノット前後の相当速い場合は，速度の大きさに較べ網糸の比重はほとんど問題にならず，また網成りも天井網等上網部は流れに対し水平もしくは前部だけが曲折直立しそれ以後の網面は波状を呈するか，最悪の場合としては天井前部が水平以下に降下することも考えられ，この部に揚力は働かず却って曲折垂下等を更に助長させ網口を低下させる結果となる。

従って網地の適切なる配備といってもそれらの効果が充分発揮できるような網具の設計法をあらかじめ見出すことが何より先決問題であるというべきである（この方法については次報で報告する）。

## 要　　約

以上網口の高さに影響すると考えられる基礎的諸要因について，実験並びにその検討を行なったのであるが，それらを要約すると次のようにいえる。

1）両船間隔が300 m（両手木間隔30 m）附近より狭い範囲では，その広狭により網口の横並びに高さの方向の拡がりとも，互に逆にではあるが相当増減する。しかし 300 m 以上の範囲ではその広狭は網口にほとんど影響せず常にほぼ定状をなしている。

2）曳網速度が2ノット附近よりおそい範囲では，その速度の遅速により網口の高さは大きく高くまた低下するが2ノット以上になると，速度の大きさにかかわらず網口はほぼ定状を保つ。なお網口の横方向の拡がりは速度の影響はなく常に一定である。

3）浮子類の浮揚力を多少増減しても網口の高さはあまり変化しない。即ち極めて大きい浮揚力を強制的に網に与えても，それは網具全体の浮上を促進さすだけで網口の高さは既に他の構成上の要因により定まっているものである。

4）曳網中の漁具の網成り並びに網口の高さは，網具自体の構成方法如何による。基本的にはヘッド・ロープとグランド・ロープにかかる張力比を減ずること，手木の長さを長めること，或いは網具の各部に適切な網地を撰択配備すること等でそれぞれ網口を高め，或いは網成りをととのえることにある程度の効果はみられるが，それぞれ各種の制約を受けてたいした成果は期待されない。しかし総合的にこれらの特質を充分生かすよう工夫し，網具の設計を改良するならば大いにその成果も期待できるので，今後の課題はこれをいかに具現するかにある。

終りに本実験について，終始ご協力をたまわった日本水産（株）並びに日本漁網船具（株）の関係各位に深甚の謝意を表する。

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# 網糸相互間の摩擦熱について※

深　沢　文　雄

## On the Relation between Frictional Heat and Durability in Mutual Friction of Netting Threads※

By

Fumio Fukasawa

In the wearing process of netting threads caused by the mutual friction, the effect of frictional heat is one of the important factors.

The abrasion of threads on each side increases till the thread wears off by frictional heat. The abrasion of threads has much to do with the durability against heat of threads. The experiments described in this paper suggest that the frictional properties of synthetic fibres under light loads are better than those of vegetable fibres, but they are reverse under heavy loads. The results are shown in Table ( 2 ) and Figures ( 2 )—( 9 ).

The observations can be represented by the following forms:

$$(\theta - \theta_0) = A(e^{at} - e^{-bt}) \quad \cdots\cdots (1)$$

$$W/T = B\tau^{\gamma t} \quad \cdots\cdots (2)$$

where A and B are constants. Equation ( 1 ) shows the relation between the thread temperature ( $\theta - \theta_0$ ) raised from the air temperature $\theta_0$ by friction and the sliding time t. Equation ( 2 ) shows the relation among the tensile strength T of the thread, the load W and the breaking time $\tau$.

Figures ( 7 ) to ( 9 ), for examples of effect of frictional heat, show the transections of threads which were pulled to be burnt out by flame, or broken by a tensile strength tester, or worn away by friction.

The general arrangement of the appratus to measure the temperature with the thermocouple is shown in Figure ( 1 ). In this figure the upper thread fixed both its ends met at right angles with the lower thread, and the lower thread can slide on its runway and also be movable by the use of a motor.

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## 緒　　言

著者はさきに合成繊維製網糸と他物質（B. S. No. 20）の極軟鋼線との摩擦について実験し報告[3]した。その結果，網糸は摩擦熱により摩擦個所の温度が上昇し摩耗が大きいことがわかった。最近ではサラン，アミラン等の単独繊維からなる網糸を使用する外に各種の繊維を混紡した網糸が使用され，同種或いは異種の2本の網糸を互に接触させて使用することが多い。この場合網糸の抗張力の外に摩擦による影響を考慮する必要がある。耐熱性において天然繊維の綿糸等より劣る合成繊維製の網糸では，摩擦熱の影響について考えることは大切なことであると思う。

## 実験方法および材料

（1）実験に使用した装置は第1図に示す通りである。網糸の往復運動の速度は 10 cm/sec，5.0 cm/sec，3.0 cm/sec の3種類に変速出来るようになっている。温度測定用の熱電対の一つの接点はジュワー瓶の中

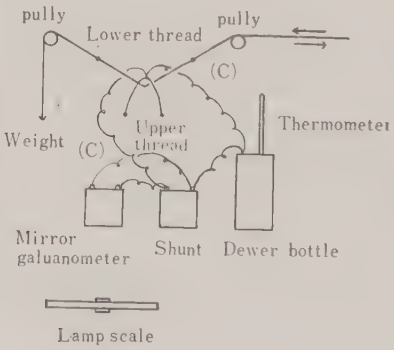



Fig. 1. Schematic diagram of wear tester. The lower thread can slide on its runways and is driven by a motor at a linear speed of about 5 cm/sec. (C), Cu-Constantan thermocouple.

で 0°C に保たれ他の接点は下糸（往復運動する試料の網糸）と上糸（固定された試料の網糸）との摩擦個所の上方で，上糸の表面に接着剤で固定されている。この装置の熱電対は，銅ーコンスタンタン線（0.16φ）で，反照検流計には感度 $2.2\times10^{-10}$ A，$3.3\times10^{-8}$ V，周期 7.4 sec のものを使用した。

Table 1. Specification of threads used for the experiment.

| Kind of material | Number or Deniel | Ply/No. of yarn | Number of twiste per 10 cm of length | | Tensile strength Kg |
|---|---|---|---|---|---|
| | | | Upper twiste | Lower twiste | |
| Amilan | 210D | 3/75 | 12.0 | 23.0 | 65.3 |
| Saran | 1000D | 3/54 | 7.3 | 7.6 | 66.5 |
| Gremona No. 5 | 500D | 3/51 | 10.0 | 11.0 | 55.0 |
| Cremona Manryo | 20′ S | 3/81 | 9.1 | 23.0 | 62.8 |
| Polyethylene | 500D | 3/48 | 11.8 | 14.6 | 73.9 |
| Cotton | 20′ S | 3/90 | 12.0 | 29.0 | 41.6 |

| Kind of material | *Softeing point °C | *Second order transition temperature °C | *Specific heat cal/g °C | Melting point °C |
|---|---|---|---|---|
| Amilan | 210 | 80 | 0.46 | 212 |
| Saran | 116～137 | 70～80 | 0.32 | 160～170 |
| Cremona No. 5 | 190～200 | 70～90 | | 220 |
| Cremona Manryo | 190～200 | 70～90 | | 220 |
| Polyethylene | 110 | | 0.53 | 140～150 |
| Cotton | | | 0.32 | |

*Taken from reference

（2）本実験で使用した網糸の試料は，見掛上太さおよび抗張力が大体同一程度のものを選んだ。その種類はアミラン，クレモナ5号（長繊維），クレモナ万漁（短繊維），サラン，ポリエチレン，綿糸の6種類で各網糸の性能は第1表に示す通りである。実験時の温度は 25～31°C，湿度は 73～81 % であった。摩擦速度は 5 cm/sec で行なった。

## 実験結果および考察

アミラン等各網糸はその一つが固定され他の網糸で摩擦し，その摩擦個所の温度上昇と時間 t との関係，破断時の温度，網糸の破断に到るまでの時間等の測定を各網糸について行なった。

**（1）摩擦個所の温度上昇と時間 t とについて**

この両者の関係は固定した上糸に接着された熱電対から 10秒毎に網糸の温度 $\theta$ を測定することにより求めた。摩擦により発生した熱量は上糸，下糸の両者に分配される。その分配比は網糸の温度伝導率 k により この k は各網糸を構成する繊維の熱伝導率，含水量，比熱および密度等によって定まる値である。k 値は前報告[3]で求めたように繊維間は含有される空気の影響を無視すると，

$$k=\lambda_1(v_1)+\lambda_2(v_2)/c_1\rho_1(v_1)+c_2\rho_2(v_2)$$

から求めることが出来る。但し（$c_1$，$\rho_1$，$\lambda_1$），（$c_2$，$\rho_2$，$\lambda_2$）は繊維および水の比熱，密度，熱伝導率であ $v_1$，$v_2$ は繊維および水の容積比（%）である。k 値の大きさは計算するとアミラン，クレモナ万漁，ポリエチレン，リレモナ5号，綿糸，サランの順となる。同種類の網糸同士では熱量分配は等しくなる。いま P を上糸と下糸間の接触圧力，$\mu$ を摩擦係数，v を摩擦速度，$\theta$ を網糸の温度，$\theta_0$ を周囲の空気の温度，$C_A$ を繊維の熱容量とすれば摩擦個所の温度上昇 $\Theta=(\theta-\theta_0)$ は次のようになる。

$$\frac{d\Theta}{dt}=-\frac{K}{C_A}\Theta+\frac{P\mu v}{JC_A}\quad J：熱の仕事当量$$

$$\mu=\mu_0 f(t)\qquad 但し\ \mu_0\ は最初の摩擦係数$$

$$\frac{K}{C_A}=\alpha,\ \frac{P\mu_0 v}{JC_A}=\beta\qquad とおけば\qquad \frac{d\Theta}{dt}=-\alpha\Theta+\beta f(t)$$

$$\therefore\ \Theta=\{\beta\int f(t)e^{\alpha t}dt+C\}e^{-\alpha t}\quad\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\ (a)$$

C：積分常数

次に測定値より $\Theta$ と t との関係を第2－5図から求めてみると，

$$\Theta=A(e^{at}-e^{-bt})\quad\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\ (1)$$

なる実験式が得られる。このことは（a）式で $f(t)=e^{\gamma t}$ とおいて t＝0 で $\Theta$＝0 の条件で求められる

$$\Theta=\frac{\beta}{\alpha+\beta}(e^{\gamma t}-e^{-\alpha t})$$

と一致することがわかる。第2－5図の曲線の形状は各網糸の性質により異るが次の3つの場合に分けて考

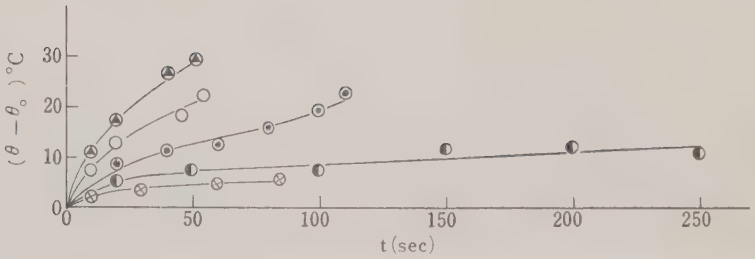



Fig. 2. Relation between $(\theta-\theta_0)$ and duration of netting threads against cotton.
▲—Cremona No. 5 (W=2 Kg) ○—Cremona Manryo (W=2 Kg)
◉—Amilan (W=2 Kg) ⊗—Saran (W=0.5 Kg)
◐—Polyethylene (W=2 Kg)

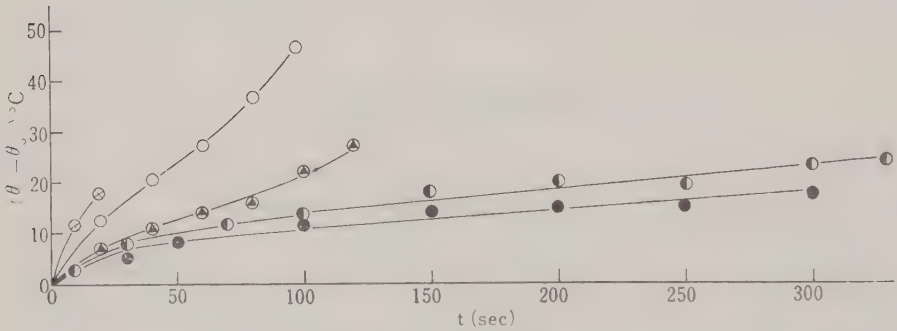



Fig. 3. Relation between $(\theta-\theta_0)$ and duration of netting threads against Amilan.
▲—Cremona No. 5 (W=3 Kg) ○—Cremona Manryo (W=2 Kg)
◐—Polyethylene (W=2.5 Kg) ⊗—Saran (W=1 Kg)
●—Cotton (W=1 Kg)

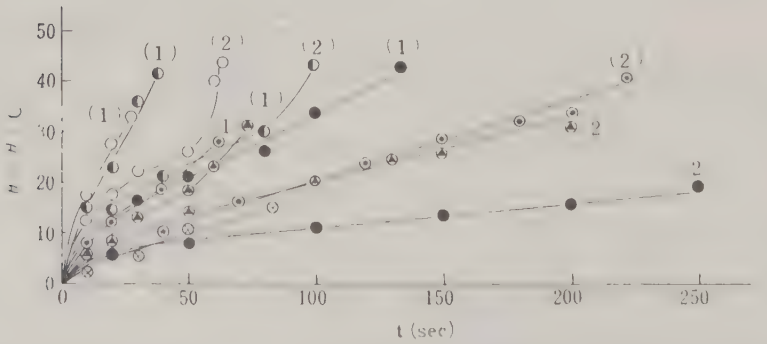



Fig. 4. Relation between $(\theta-\theta_0)$ and duration in mutual friction of netting threads.
◐—Polyethylene (1)—W=6Kg (2)—W=4 Kg
●—Cotton (1)—W=3Kg (2)—W=2 Kg
▲—Cremona No. 5 (1)—W=2 Kg (2)—W=1 Kg
○—Cremona Manryo (1)—W=2 Kg (2)—W=1 Kg
◉—Amilan (1)—W=3 Kg (2)—W=2 Kg
⊗—Saran W=0.5 Kg

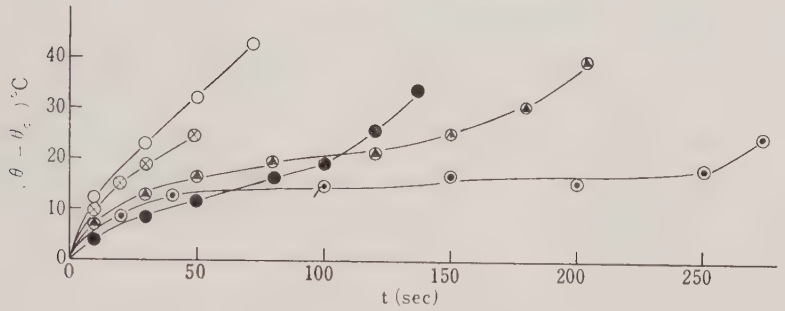



Fig. 5. Relation between ( $\theta - \theta_0$ ) and duration of netting threads against polyethylene (W=3Kg) worn away by other netting threads except Saran.
▲—Cremona No. 5　○—Cremona Manryo　⊗—Saran
◉—Amilan　●—Cotton

えることが出来る。

（イ）固定された網糸（第1図の下糸）と動く網糸とが時間の経過につれて同程度に摩擦する場合

（ロ）固定された網糸が動く網糸よりも時間の経過につれて摩耗が激しい場合

（ハ）（ロ）の反対の場合

一般には摩擦の始った初期ではΘは大体直線的に上昇し，次第に定常状態に近き（1）式で示される形となる。（ロ）の時は熱電対の位置と摩擦個所の距離が短くなるのが速いので（イ），（ハ）に比べてΘの上昇は急である。更に熱による摩耗の影響が大となればなる程急速に温度は上昇する。特に荷重Wが大(Pが大)となると最初から熱による摩耗の影響を受けるので定常状態にならず破断まで殆んど直線的に変化する。第5図ではポリエチレンを固定した時サランを除いた他の網糸（W=3 kg）によってポリエチレンは破断されている。これは（ロ）の場合をよく示している。（イ），（ハ）の場合は定常状態に近き，すなわち温度の上昇の度合が急激でなく（1）式とよく一致する。同種類の網糸相互間の摩擦では（イ）の場合が多く第4図に示す通りである。第2－3図は綿糸，アミランを固定し，動く他の網糸の方が破断する場合で（ハ）の状態を示しており（1）式と一致する。しかし，上記（イ），（ロ），（ハ）の何れの場合になるかは網糸の種類の組合わせによるばかりでなく，網糸に与える張力Wにもよる。綿糸を固定した時Wが大であると合成繊維の網糸の方が破断するので（ハ）の場合である。これは綿糸は温度による抗張力の減少はあっても熱による摩耗の影響を考えなくてもよく単なる機械的摩耗についてのみ考えればよいからである。しかしWが小さくなると発生する摩擦熱量が少く温度上昇が僅かであるため，アミラン等の網糸は熱影響を受けることが殆んどなくなるので，固定されている綿糸の方が摩耗が激しくなり（ロ）の場合となる。また，第4図の同種類の網糸相互間の摩擦ではWが大となるに従い（イ）から（ロ）の状態に移行し，曲線は定常状態の間が短くなり直線的部分が多くなっていく。アミラン，クレモナ，ポリエチレン等はこの性質を示している。サランは W<0.2 kg の場合では綿糸を破断する。それ以外ではWに無関係に他の網糸により破断され，空気中では熱による摩耗の影響がもっとも大きく今回の測定のWの範囲内（0.2~6.0 kg）では，Θの変化は定常状態に達しないうちに破断する。綿糸同士の摩擦ではΘはWの大小に関係せず（1）式に従う。

**（2）網糸相互間の摩擦強弱について**

いま組合わされた2種類の網糸の摩擦では，破断されてしまった網糸の方が他の網糸より耐摩耗性が劣っていると判断することも一つの目安であると思う。網糸の最初の抗張力Tの大なるものが必ずしも摩擦に対する耐久力が大であるとは言えない。第2表は各網糸を組合わせて摩擦させた時その破断時間よりみた摩擦の強弱を表わしている。

各網糸の強弱の順序は第2表からアミラン，クレモナ万漁，クレモナ5号，ポリエチレン，サランとなる。

Table 2. Toughness of mutual friction of netting threads.
+ : Toughness over the other netting thread.

| | Amilan | Saran | C. No. 5 | C. M. | Poly. | Cotten |
|---|---|---|---|---|---|---|
| Amilan | | + | + | + | + | − w＞1.0 kg<br>+ w＜1.0 kg |
| Saran | − | | − | − | − | − w＞0.2 kg<br>+ w＜0.2 kg |
| Cremona No. 5 | − | + | | − | + | − w＞1.0 kg<br>+ w＜1.0 kg |
| Cremona Manryo | − | + | + | | + | − w＞1.5 kg<br>+ w＜1.5 kg |
| Polyethylene | − | + | − | − | | − w＞0.5 kg<br>+ w＜0.5 kg |
| Cotton | + w＞1.0 kg<br>− w＜1.0 kg | + w＞0.2 kg<br>− w＜0.2 kg | + w＞1.0 kg<br>− w＜1.0 kg | + w＞1.5 kg<br>− w＜1.5 kg | + w＞0.5 kg<br>− w＜0.5 kg | |

綿糸は高荷重では合成繊維の網糸より強く低荷重では弱い。

**（3）破断時間 τ について**

荷重Wと破断時間 τ との関係は，実験結果によれば第6図に示す通りである。但し第6図では異種の網糸

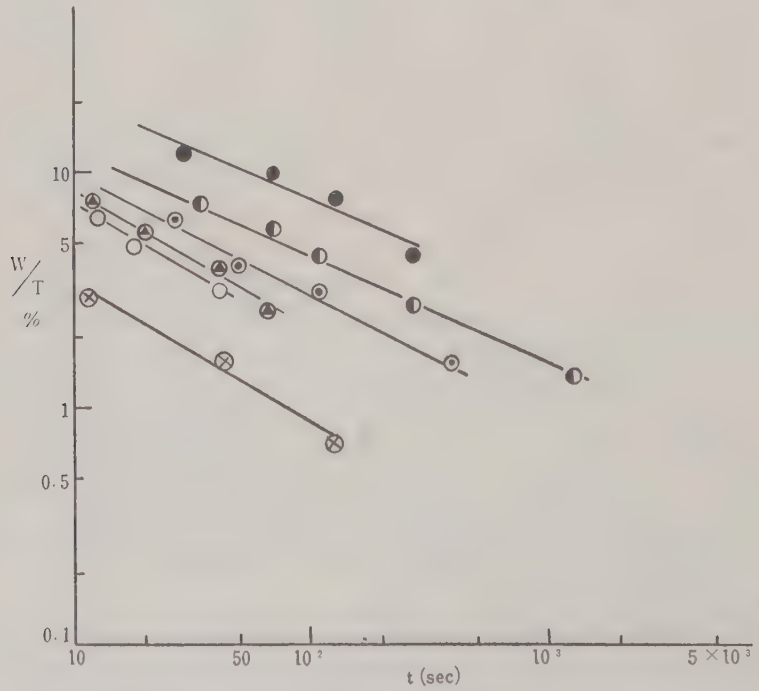



Fig. 6. Relation between W/T (%) and duration of netting threads against cotton.
▲—Cremona No. 5　○—Cremona Manryo　⊗—Saran　◉—Amilan
◐—Polyethylene　●—Cotton

のグラフを比べる便宜上最初の抗張力Tで割った W/T を使った。第6図から実験式を求めると，

$$T/W = B\tau^{\gamma'} \qquad \gamma' < 0$$

なる2次曲線で表わされる。サランの抗張力はポリエチレンに次いで大であるが第6図ではサランの破断時間は最小である、綿糸の抗張力は他の網糸に比べて最小であるが破断時間は大であるのは，熱による摩耗の影響がないことを示している。

**（4）摩擦熱による摩耗が進行する温度について**

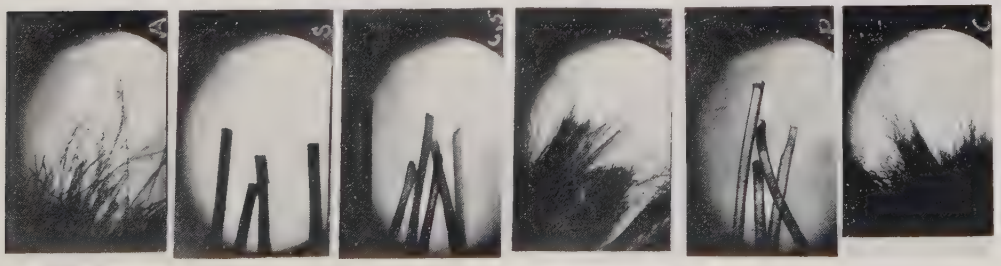
異種の網糸相互間の摩擦では前述したように摩擦によって発生した熱量は各網糸の温度伝導率により両者に分配される。同種類の網糸相互間では熱量は等分に分配されるから，実際に測定した$\Theta$の2倍の温度が網糸の接触面に影響していることになる。従って摩擦熱による摩耗の急激に始まる温度（$2\Theta+\theta_0$）を測定値より計算すると（第4図参照）アミラン，クレモナ万漁および5号は何れも 80°C，ポリエチレンは 90°C，サランは 60°C位であって，これは各合成繊維の第2次転移点附近である。第4図によれば各網糸は上記温度に達した場合間もなく破断する。これは摩耗が急速に進行するから接触面積は減少し，又表面状態も変化してくるので，それ以上の温度が余り上昇しないうちに破断するものと思われる。Wが小である場合には，上記温度に達してから更に僅か温度が上昇して破断している。これは測定装置による温度の伝い方のおくれによるためと思われる。更にWが小さいときは上記温度に達することなく単なる機械的摩耗のみで破断に到る。

**（5）網糸の切断個所の繊維の形態について**

合成繊維で構成されている網糸は，前述したように熱影響をうけるのでその切断個所の繊維の横断面は次のような3種類の形態を示している。

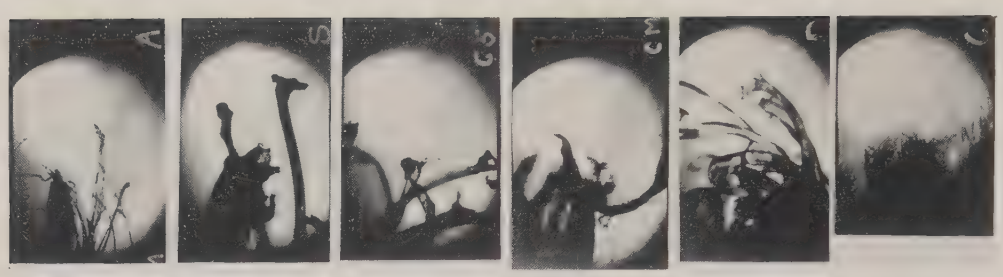
Amilan　Saran　Cremona No. 5　Cremona Manryo　Polyethylene　Cotton

Fig. 7. The transections of threads pulled to be burnt out by flame.



Amilan　Saran　Cremona No. 5　Cremona Manryo　Polyethylene　Cotton

Fig. 8. The transections of threads broken out by tensile strength tester.



Amilan　Saran　Cremona No. 5　Cremnoa Manryo　Polyethylene　Cotton

Fig. 9. The transactions of threads worn off by friction of netting threads against Cotton (W=3 Kg).

（イ）繊維の先端が熔融して円くなる。

（ロ）摩擦個所の温度上昇によりその部分が軟化し，接触圧力が作用するので押しつぶされて切断された繊維の端が平になり不規則の形をとる。

（ハ）細い繊維で構成されている網糸では（イ），（ロ）の状態の繊維が相互に密着して固まって切断する。

第7図は網糸に張力をかけながら焔で焼切った場合の繊維の横断面でアミラン，サラン，リレモナ5号，ポリエチレン等は先端が円く熔融した個々の繊維と，それらがまた密着して固まった部分とが混っている状態である。特にアミラン，クレモナ万漁では密着している部分が多い。綿糸は熔融することがないから繊維同士が密着して固まることがなく，ばらばらでその先端がただ黒く焦げるだけである。第8図は抗張力試験機で破断した場合で各網糸の繊維の切口は何れも刃物で切断した時のようにきれいな横断面を示している。第9図はW=3 kg の荷重で綿糸に対して摩擦させたときの各網糸の破断した場合の横断面である。綿糸は抗張力試験機で破断した時と殆んど同一で，ただその切口が不規則になっているだけである。アミラン，クレモナ万漁は（ハ）の場合に相当している。サラン，クレモナ5号，ポリエチレンでは繊維が比較的太いため（イ），（ロ）の状態が大部分を占め残部が繊維の密着している状態である。第7図と第9図とから綿糸を除いた他の網糸ではその横断面が非常によく似ており，摩擦熱の影響があることを示している。一般にWが大きくなると繊維の熔融密着した部分が多くなる。Wが小さくなるとサラン，クレモナ5号，ポリエチレン等は（ロ）の状態が多くなる。アミラン，クレモナ万漁では（ハ）の部分より（ロ）の部分が多い状態となる。

## 要　　約

（1）摩擦により発生した熱量は（（P, μ, v）に関係する。vが一定ならば同一種類の網糸では，抗張力の大小（繊維のデニールが同一ならその本数の多少）に拘わらずその摩耗及び破断時間は，荷重即ち接触圧力の大小による。そのことは，網糸の耐摩耗性は耐熱性により左右されることを表わしている。（第4図参照）実験の結果によれば，各網糸の組合せで摩擦で相手を破断する点から考えたその耐摩耗性の強さは，アミラン，クレモナ万漁，クレモナ5号，ポリエチレン，サラン，綿の順となる。この順位は各繊維の軟化点（第1表参照）の大小に関係していることがわかる。クレモナ万漁及び5号は，短繊維であるか長繊維であるかがその耐摩耗性に影響してくるものと考えられる。

（2）ポリエチレンはサランを除いた他の網糸から破断されるが，表面が非常に滑らかでμが小さいのでその破断時間が大きいのが特色である。（第2，3図参照）

（3）合成繊維の網糸は低荷重（Pが小）では，天然繊維より耐摩耗性は秀れているが，高荷重ではその

逆である。

（4）熱による摩耗は，各繊維の第2次転移点附近から急速に進行する。

終りに御指導を賜った本所の神谷鑓吉教授に深謝する。

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# 魚類プロテアーゼに関する研究 (第X報)※

## ビンナガ鮪幽門垂プロティナーゼの構成について

藤　井　　実

Studies on the Protease of Fishes (X)
On the Components of the Proteinases in the Enzyme solution
Extracted from Powder of Pyloric caeca of Long
Fin Tuna *Thunnus alalunga*※

By

Minoru FUJII

In this investigation, the author reported on the classification of the crystalline proteinase as trypsin (called as Trypsilin), Crystalline Bacterial Al-Proteinase and refined enzyme preparation as Pronase and Bioprase by means of the ratio of nitrogen of the lower compounds-fragment to the total soluble nitrogen decomposed from the casein by action of enzyme, and compared the activities of refined enzyme fractions which were separated by aluminium-hydroxde (Cγ-type) from the refined protease sample, which was made by using ammonium-sulphate and acetone (Fig 1.) from the water extractives of pyloric caeca of long fin tuna to the above described enzyme type.

The results were as follows:

The three fractions were separated from the enzyme solution extracted from powder of pyloric caeca:

The first fraction was analogous to the mammalian proteinase as trypsin and the second to the Crystalline Bacterial Al-Proteinase in bacteria but the third not analogous to the formers and showed the characteristic activities.

魚幽門垂は腸の一部が分化したものといわれ胃の幽門部の直後に存在する魚類特有の消化器官で胃と腸の接着部に開口するものであり，その主要なる分泌物である蛋白分解酵素群が蛋白消化に主要な役割を演じていることは疑のない所である。従ってその分泌酵素を出来るだけ細かく分割してそれぞれの作用機能を知ることが出来れば幽門垂分泌液の蛋白分解機構を明きらかとすることが出来ると共にその応用の基礎的知見を

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も得ることが出来ると考える。而して分割したそれぞれの精製酵素の基質蛋白に対する分解能を知るには標準とする酵素の分解能に比較するのがもっとも簡単であると思われるが，幸い今日結晶プロティナーゼが数種類市販せられるようになったので，これらを標準とすることにした。

結晶プロティナーゼとして哺乳動物（牛，豚）の膵臓より得られたトリプシリン（商品名）および菌体より得られたる結晶性—細菌—Al—プロティナーゼ（Crystalline-Bacterial-Al-Proteinase：商品名）が入手出来たので，先ずこれらのカゼイン蛋白に対する分解能を検討し更に参考のため結晶性ではないが高度精製の粉末酵素剤に就いても分解能を検討し，次に幽門垂プロテアーゼを硫安およびアセトン処理し，更に水酸化アルミニウム（Cr—型）を使用し，種々の条件下で吸着および溶離操作を行なって得た三分画について，それぞれのカゼイン分解能を測定し，結晶プロティナーゼのそれに比較した所，類似するものと相異なるものが存在することが明きらかになった。

### 1）結晶プロティナーゼおよび精製粉末酵素剤のカゼイン分解能に就いて

**酵　素　剤；**

a）Trypsilin（商品名：T-Pase と略する）

本品は持田製薬ＫＫより出されている結晶製品である。その力価は1錠剤 10,000 H. U. M（会社の定めた力価）である。

b）結晶性—細菌—Al—プロティナーゼ（商品名として Crystalline Bacterial Al-Proteinase：C. B. Al-Pase と略する）

本品は長瀬産業ＫＫ尼崎工場製造のもので$20\times10^4$PUN/Vial（会社の定めは力価）の結晶である

c）ビオプラーゼ（$NPN_4$）……商品名

上記b）と同一会社製で 20,000 PUN/g の作用力といわれ中性プロティナーゼである。b）と同じく Bac. subtilis var Bioters より製造されたものという。

d）プロナーゼ（商品名である。P-Nase と略する）

本品は科研ＫＫ製品で St. griseus より抽出精製されたものでその力価は 50,000 PUK/g（会社の定めた力価）といわれるが，これも中性プロティナーゼである

## 実験条件および測定方法

各種酵素剤を適量秤量しこれに pH 7 或いは 8.5 の緩衝液を適当量加えて溶解しそのまま或いはこれを更に遠心分離して清澄液を得てこれを酵素試料とする。

5％カゼイン 10 cc に緩衝液（pH 7 或いは 8.5）30 cc を加えて更によく pH を調製した後 45°C に温ため，これに適量の酵素液を添加し更に蒸溜水（45°C）を加えて全量を 50 cc となし一定時間（ここではすべて1時間）作用させた後 20％の三塩化酢酸液 16 cc を添加して酵素作用を止め未消化蛋白質を除去し，濾液を 100 cc にしてその一定量を分析に供する。

P-N……添加した酵素試料溶液中に含有される蛋白態窒素量を示す。

N-P-S-N……上記酵素処理濾液に存在する所謂非蛋白態可溶性窒素量を示す。

Poly-N……上記酵素処理濾液の一定量（20 cc を使用した）を加熱しその中に溶存する三塩化酢酸を除去し液量を約 9 cc 前後となしこれに 5％燐タングステン酸（5％硫酸溶液）を添加する。しかるときは白色沈澱を生ずる。更にこれに蒸溜水を加えて全容量を再び 20 cc となした後遠心分離を行なって上澄液を得，その上澄液について Folin 試薬による呈色を行わしめ日立製作所製 EPU 2型分光々度計により波長 280 mμ を使用して比色定量を行なって得られる窒素量である。

Act/P-N……カゼイン基質に酵素試料を添加反応せしめて得られる

N-P-S-N を同酵素試料中の P-N で除したものである。従ってこれは酵素態蛋白 1 mg（または 1 g）

により基質より生成される N-P-S-N (mg または g) を示すものでその数値の大小は酵素作用力の大小を示す。

$\text{Poly-N}/\text{N-P-S-N} \times 100$……酵素作用により得られた N-P-S-N のうち更に低分子（所謂プロテオーズ，ペプトンと称する高分子化合物より以下の窒素化合物全部を意味する）の占める割合を示すものである。

次に実験結果を Tabe 1～6 で示す。

Table 1. Activity of trypsin on the casein.

| pH / Incubation time(mins.) / Value of measurement | 8.5 | | |
|---|---|---|---|
| | 30 | 60 | 90 |
| Act/P-N | 338 | 430 | 520 |
| PolyN-/N-P-S-N × 100 | 10 | 11 | 11 |

Note:
Act……Nitrogen (mg or g) of soluble compounds which were decomposed from casein by action of enzyme-N. (mg or g).
P-N……Protein-nitrogen (mg or g) in enzyme-preparation.
N-P-S-N……Non-protein soluble nitrogen (mg or g) in the reaction solution.
Poly-N……Polypeptide-nitrogen (mg or g) (include $NH_2$-N, amide-N and $NH_3$-N) in the reaction solution.

Table 2. Activity of Crystalline Bacterial Al-Proteinase on the casein.

| pH / Incubation time(mins.) / Value of measurement | 8.5 | | |
|---|---|---|---|
| | 30 | 60 | 90 |
| Act/P-N | 587 | 795 | 944 |
| Poly-N/N-P-S-N × 100 | 22 | 19 | 23 |

また反応液の pH が7および8.5の場合の比較を行なった結果が第3および4表である。

Table 3. Activity of trypsin on the casein.

| pH / Incubation time(mins.) / Value of measurement | 7.0 | 8.5 |
|---|---|---|
| | 60 | 60 |
| Act/P-N | 450 | 408 |
| Poly-N/N-P-S-N × 100 | 11 | 12 |

Table 4. Activity of Crystalline Bacterial Al-Proteinase on the casein.

| Value of measurement \ pH | 7.0 | 8.5 |
|---|---|---|
| Incubation time(mins.) | 60 | 60 |
| Act/P-N | 934 | 1035 |
| Poly-N/N-P-S-N × 100 | 20 | 20 |

次に結晶ではないが高濃度酵素粉末として商品化されているビオプラーゼ（$NPN_4$……商品名）およびプロナーゼ（P-Nase と略する）について同様に測定値を求めて第5および6表を得た。

Table 5. Activity of Bioprase on the casein.

| Value of measurement \ pH | 7.0 | 7.0 |
|---|---|---|
| Incubation time(mins.) | 30 | 60 |
| Act/P-N | 254 | 414 |
| Poly-N/N-P-S-N × 100 | 30 | 31 |

Table 6. Activity of Pronase on the casein.

| Value of measurement \ pH | 7.0 | 7.0 |
|---|---|---|
| Incubation time(mins.) | 30 | 60 |
| Act/P-N | 43 | 49 |
| Poly-N/N-P-S-N × 100 | 57 | 65 |

以上の諸実験の結果を見るに、カゼインを基質とした場合、アルカリ性反応（pH 8.5）において Poly-N/N-P-S-N × 100 の値は T-Pase の場合：10～11，C. B. Al-Pase：19～23 で後者は前者の約2倍である（第1および2表）。そして両者とも反応時間の長短に関係なく同一値を示している（第1および2表）。これに反して Act/P-N の値は反応時間の長い程大きい数値を示したがこれは当然なことである。次に第3および4表の示す所によれば基質反応液の pH が異なる場合すなわち中性（pH 7）およびアルカリ性（pH 8.5）の場合においても Poly-N/N-P-S-N の値は略同一値を示した。そして Act/P-N の値は T-Pase では中性側でやや強く，C-B-Al-Pase ではアルカリ性側で強かった。

以上の諸測定値の結果から，Poly-N/N-P-S-N × 100 の値は反応液の pH および反応時間に関係なく酵素に特有の数値を示すものと考えることができる。而して両酵素（T-Pase 及び C・B. Al-Pase）共に結晶体であるから現在の製造過程が変らない限り，その Poly-N/N-P-S-N の値は上述のような値を示すこと明らかで，両酵素の示す数値の差異は明らかに両酵素のカゼインに対する分解機構の本質的差異に基くものと考えることも決して無理ではないと考えられる。

次にビオプラーゼ及びプロナーゼについてみるに Poly-N/N-P-S-N×100 の値は反応時間に関係なく夫々30及び60を示した。両酵素剤共結晶体でないので，なお数種類の酵素の混在が考えられるのであるが，$NPN_4$ の Act/P-N は T-Pase のそれと殆んど同一値を示したのにも拘わらず Poly-N/N-P-S-N×100 の値は $NPN_4$ の方が約3倍であった。更に P-Nase の Poly-N/N-P-S-N×100 値は約65（60分の場合）という高い値を示すのに Act/P-N の値は約49で T-Pase のそれの約½であることはそれぞれこれら酵素剤の特徴を示すものであると考えることができる。

### 2）精製魚幽門垂プロテアーゼのカゼイン分解能について

魚幽門垂プロテアーゼ試料として鯖幽門垂のアセトン・エーテル処理粉末を使用した。その精製法は次の通りである。即ち粉末の一定量に pH 8.5 の緩衝液を加えて抽出を行いその抽出液を微酸性（pH 5.2）にした後これに固形硫安を加えて¾飽和度となし，生じた沈澱を少量の水（pH 7 の Mc Ilvaine 緩衝液使用）に溶かしこれにアセトンを加えて40％となし生じた沈澱を除き上澄液に更にアセトンを加えて70％となし生じた沈澱を分離しこれを水（pH 7 の緩衝液）に溶かし再びアセトン処理を繰り返す。アセトン処理を2回繰り返して得た沈澱をできるだけ少量の pH 7 の水（緩衝液）にとかしこれを3部に分かちそれぞれに水酸化アルミニウム（Cγ型）の一定量及び pH 5，7及び 8.2 の緩衝液一定量を添加し，更に pH をよく規正した後攪拌吸着を行い，Cγ一吸着部を水部と分離した後これらにそれぞれ酸性，中性或はアルカリ性緩衝液を添加して攪拌溶離を行いそれぞれ溶離された酵素液について上述の方法に従ってカゼイン分解能を測定した。

次に酵素試料の分画方法及び各分画試料のカゼイン分解能を示す。

a）pH 5 で吸着し pH 7 及び 8.2 で溶離した場合

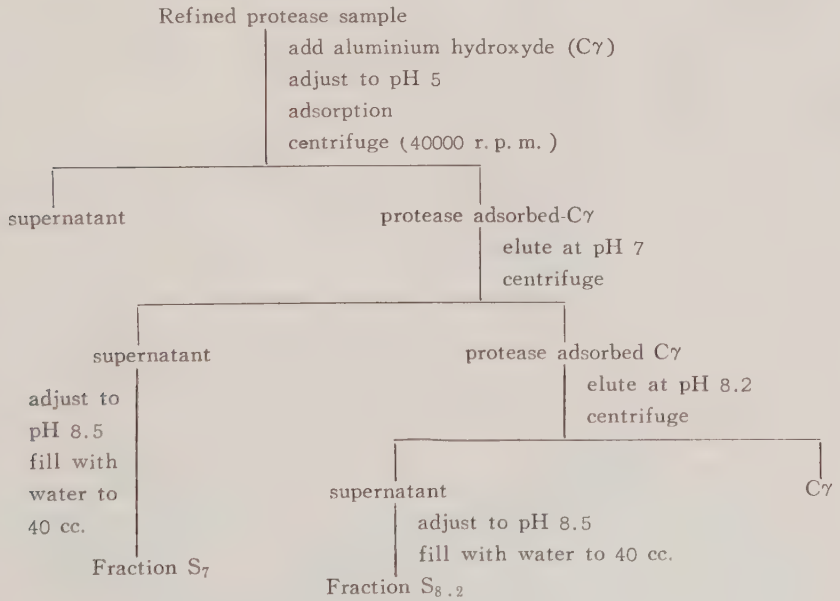


Fig. 1. Showing the preparation of refined enzyme fraction

Note : Preparation of refined protease sample

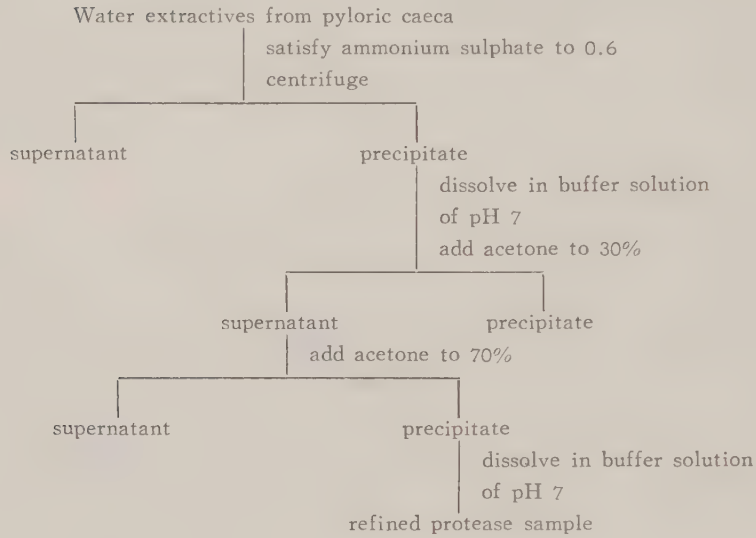


Table 7. Activity of refined enzyme fraction on the casein.

| Value of measurement \ Fraction | $S_7$ | $S_{8.2}$ |
|---|---|---|
| $\text{Poly-N}/\text{N-P-S-N} \times 100$ | 23 | 24 |

b) pH 7 で吸着し pH 5 及び 8.2 で溶離した場合

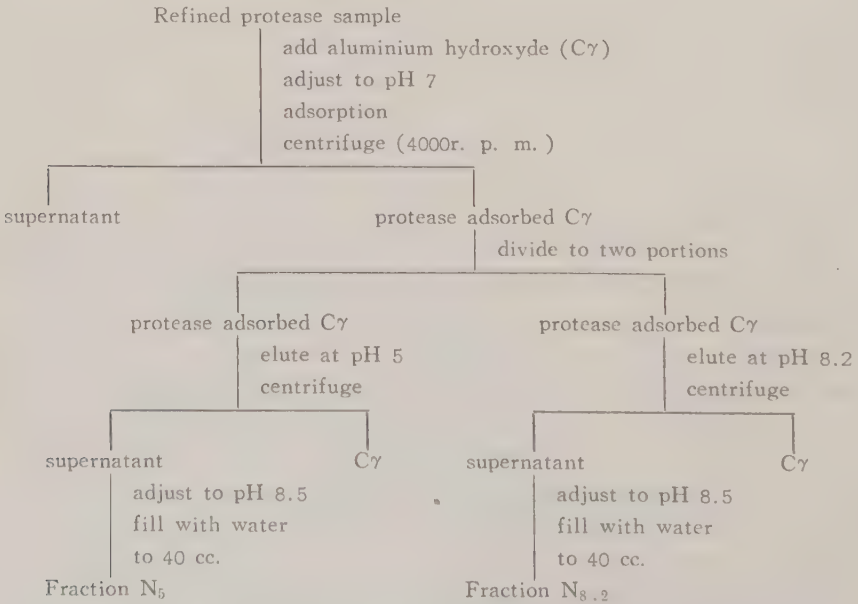


Fig. 2. Showing the preparation of refined enzyme fraction.

Table 8. Activity of refined enzyme fraction on the casein.

| Value of measurement \ Fraction | $N_5$ | $N_{8.2}$ |
|---|---|---|
| Poly-N/N-P-S-N × 100 | 15 | 15 |

c) pH 8.2 で吸着し pH 7 及び 5 で溶離した場合

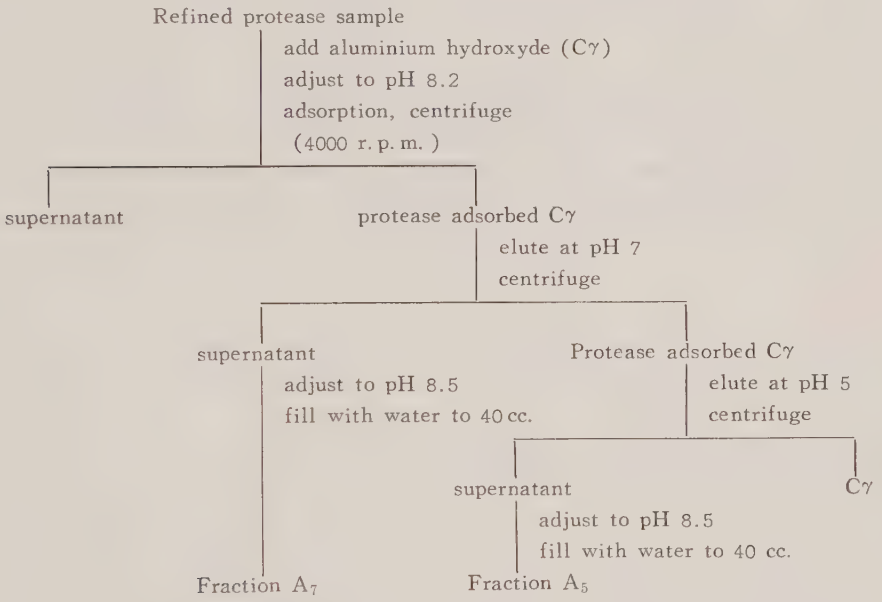


Fig. 3. Showing the preparation of refined enzyme fraction.

Table 9. Activity of refined enzyme fraction on the casein.

| Value of measurement \ Fraction | $A_5$ | $A_7$ |
|---|---|---|
| Poly-N/N-P-S-N × 100 | 10 | 13 |

以上の諸実験結果をみるに第7表においては $S_7$ 及び $S_{8.2}$ の測定値は略同値とみることができる。即ち Cγ に対して pH 5 における吸着酵素は C. B. Al-Pase のそれに近似している。又第9表より pH 8.2 における吸着酵素は $A_5$ : 10, $A_7$ : 13 であって特に $A_5$ の値は T-Pase のそれと全く同値を示した。$A_5$ 及び $A_7$ の Act/P-N の値はそれぞれ 534 及び 573 であったので $A_5$ 及び $A_7$ とも同じ型の酵素であると考えられる。即ち $A_5$ 及び $A_7$ 共に Trypsin 型であると考えられる。

次に pH 7 で吸着した酵素試料の $N_5$ 及び $N_{8.2}$ の値は共に 15 であって (Table 8) この値は上述の両結晶酵素の示した値の中間値を示した。以上の諸実験結果を総合すれば魚幽門垂プロティナーゼに対し pH 5, 7 及び 8.2 において Cγ を使用することにより少くとも 3 つの型の酵素類を分離することができることは明きらかである。即ちその一つは哺乳動物のトリプシン型であり，他の一つは細菌プロティナーゼ型と同一とみ

なされるものである。そして第三の型は上述の二者の中間的性質を示すものでこれが魚類に特有のものかどうかは更に今後の研究により確める必要があるが，とにかく魚幽門垂プロテアーゼには哺乳及び細菌プロティナーゼの両型酵素が含有され更に魚類型ともいうべき第三の型の酵素を有することは明きらかである。

## 総 括

結晶プロティナーゼ及び精製酵素剤によるカゼイン分解生成物から酵素の分類を試みた。即ち哺乳動物源であるトリプシンと細菌源の C. B. Al-Proteinase とは分解機構を異にする別個の type に属するものであり，又中性プロティナーゼであるビオプラーゼもその原料を異にするプロナーゼとは本質的に異なるものである。次に鯖幽門垂プティロナーゼを水酸化アルミニウム ($C_\gamma$ 型) により分画し，各分画のカゼイン分解能を上記各プロティナーゼのそれに比較したところ哺乳動物型プロティナーゼ及び細菌型プロティナーゼの２つの type の存在が認められ，更に両者の中間型ともいうべきプロティナーゼが存在するのを認めた。

この稿を終るに当り，種々御高見を賜った九大船津教授に対し深甚の謝意を表します。

（註：この報告の大要は昭和34年10月の日本水産学会（於大阪）において報告した。）

# 蜜豆缶詰内の寒天ゲルに関する研究—Ⅲ※

## 寒天ゲルの着色法について

小島良夫・大庭安正・白石友義・鹿田敏明

## Studies on the Agar Gel in Canned "Mitsumame" —Ⅲ. On the Method of Colouring Agar Gel.※

By

Yoshio KOJIMA, Yasumasa ŌBA, Tomoyoshi SHIRAISHI, and Toshiaki SHIKADA

The pigment of coloured agar gel in canned "Mitsumame" has often been found to dissolve in syrup and colour the other fruits for the purpose of sterilizing and storing it.

The authors have made an attempt to produce the salts of colouring matter which is insoluble and thermostable in the agar gel with a view to protecting dissolved pigment from the coloured agar gel.

The results obtained are as follows.

1. Pigment in the coloured agar gel fixed with potassium alum was dissolved out with its weakness against heat.
2. The fixing method of pigment in agar gel with cationic surface active agent was found to be most effective than with any other fixing materials.
3. Pigment dissolved from coloured agar gel coloures syrup, follows to make fruits get colour and it's concentration in syrup gradually decreased.

## ま え が き

一般に蜜豆罐詰ではその内容物の色彩効果を揚げるために，赤や緑に着色した寒天ゲルを少数混入する方法が採用されている。しかしながらこの着色寒天ゲルは罐詰製造工程における殺菌加熱のため，或いは貯蔵中シラップと寒天ゲル中の水との拡散作用により色素が溶出して褪色を来たす。

しかも溶出した色素は他の内容物であるシラップや果実を着色して蜜豆罐詰の商品的価値を低下させているのが屢々見受けられる。この着色に用いられている食用色素類は殆んど水に可溶性の酸性色素の塩であっ

※ 水産講習所研究業績　第320号，1961年1月18日 受理.
Contribution from the Shimonoseki College of Fisheries, No. 320.
Received Jan. 18, 1961.
1960年4月 日本水産学会年会（東京）にて発表

て，ゲル中網目状構造の寒天の間隙を塡した水に溶解している。

それ故，罐詰の殺菌加熱の工程中や貯蔵中に寒天ゲル内えのシラップの浸透に伴う拡散作用によって寒天ゲル中の色素が次第にシラップ中に溶出し，更に果実に接すると，その含有有機酸によって色素酸となって，その表面に沈着し呈色する。

著者等は酸性色素の塩が水の中で $MIn \rightleftarrows In^- + M^+$ のように解離し色素は負に帯電していることに着目し，よって長い炭素鎖の原子団で陽電荷を持った，例えば界面活性剤と化合させれば結合力強く容易に解離しない塩類を生成することができると考えた。

又寒天絲状分子も負電荷を帯びているので，ゲル中では界面活性剤と良く結合し，色素の固定が一層満足できると推察した。

よって著者等は一定濃度の寒天ゲル内での酸性色素と陽性界面活性剤との相互作用を吟味してその最適条件を求め，更に従来使用されている色素酸として寒天ゲル中に固定する方法[1]，又色素を三価の金属イオン，例えば $Al^{+++}$ と結合させて不溶性の金属塩をゲル中に固定する方法等を対熱，対酸的効果から比較した。

次にこれらの方法によって得た着色寒天ゲルを実際に蜜豆罐詰に使用し貯蔵中の褪色その他の変化を観察した。

その結果，寒天ゲル中に陽性界面活性剤で色素を固定した本方法が他の二方法より最も良好な効果を示したので茲に報告する次第である。

## 実　　験　I

### 試　　料

1. 赤色染料としては，日本法定色素食用赤色（11種類）がある。その内，輸出用として許可されているのは1～5号であって，本実験では一般に広く使用されている3号（Erythrosin）を用いた。

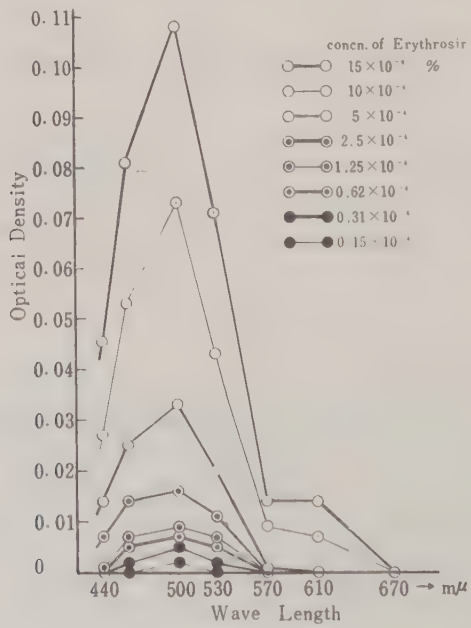


Fig. 1. Absorbance-wave length curves for solutions of Erythrosin.

2. 寒天はオゴノリ粉末寒天（ゼリー強度 750 g/cm²）を使用した。
3. 界面活性剤は一般に市販されている Benzalkonium Chloride を使用した。

**測 定 器 具**

Erythrosin の吸光度測定

着色寒天ゲルからの色素溶出度は，光電光度計（日立製作所製 MR—90 型）を使用した。

Filter の選定

C, BG, B, G, YB, O, R等各種 Filter を使用して測定し，第1図のような吸光曲線を得た。500 mμ において最高の吸光度を示したので以後の実験は BG 500 mμ のフイルターによる吸光度を測定した。

**実 験 方 法**

Erythrosin は，第2図のような構造を持ち，塩型では水溶性であるが，酸型となれば不溶性である。現

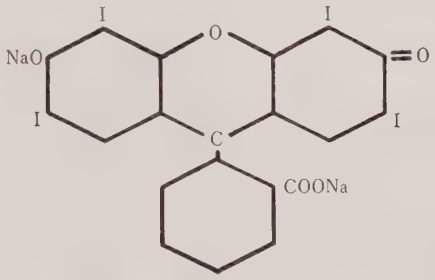


Fig. 2. Structural formula of Erythrosin.

在色素固定法として一般に広く使用されているのは，この酸型にする方法である[1]。また三価の金属と結合させて不溶性の金属塩を作る方法，更にカチオン活性剤に結合させて水に不溶の耐熱性ある塩を作る著者等の提唱した方法，これ等の方法についての比較実験を行った。

色素固定用着色寒天ゲルはオゴノリ粉末寒天 1.5 %，Erythrosin 0.03 % 濃度の寒天ゲルを調整し，これを各々 1.5 cm³ に切断して試料に供した。

**1. 硫酸アルミニウムカリウムに依る固定**

色素固定用着色寒天試料各 10 個を硫酸アルミニウムカリウム 0.01 M/L（=0.475 %）水溶液に 30°C で一定時間浸漬処理して，ゲル内に色素のアルミニウム塩を生成させた後，水 100 ml に2時間浸漬して，過剰の硫酸アルミニウムカリウムを除去した後，一部は着色寒天ゲル 10 個を水 100 ml に浸漬し，他部は糖度 25 % で pH 3.8 のクエン酸溶液 100 ml 中に入れ，殺菌加熱工程として 80°C で 20 分間加熱して一昼夜放置後，水及びシラップに溶出した色素の吸光度を測定し熱処理による影響をみた。

**2. 陽性界面活性剤 Benzalkonium Chloride に依る固定**

陽性界面活性剤は酸性染料や直接染料と結合して，不溶性の塩を作る。

染料と界面活性剤の相互作用をその色調の変化測定から屢々求められている[2]。

著者等も Erythrosin と Benzalkonium Chloride の相互関係を調べた。その結果は第3図のようである。

0.03 % Erythrosin 水溶液 10 ml に対して，0.01 % Benzalkonium Chloride 水溶液を滴下してゆくと 10 ml において，始めて色素の凝集沈澱を示し溶液の吸光度は急に低下し，Benzalkonium Chloride 水溶液 15 ml の添加において最も著しい低下を示した。16 ml 以上の滴下数においては逆に次第に吸光度の上昇を示した。

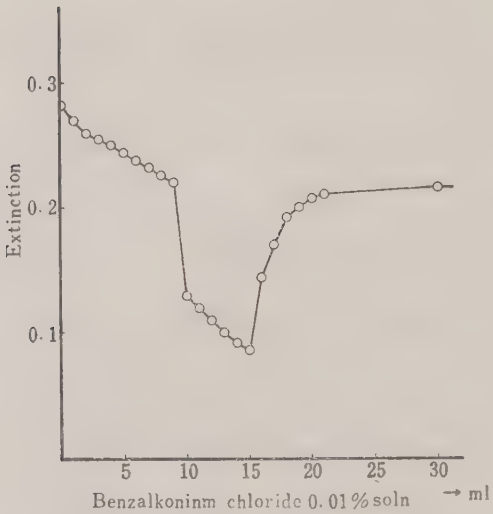


Fig. 3. Changes of absorbance (500 mμ) for solution of 10 ml of 0.03 % Erythrosin titrated with 0.01 % BenzalKonium Chloride.

これは，Benzalkonium Chloride の極めて薄い水溶液では，次のようにイオンに解離しているが，

$$\left(\text{C}_6\text{H}_5\text{—CH}_2\text{—}\underset{\displaystyle\text{CH}_3}{\overset{\displaystyle\text{CH}_3}{\overset{|}{\underset{|}{\text{N}}}}}\text{—R}\right)\cdot\text{Cl} \rightleftarrows \left(\text{C}_6\text{H}_5\text{—CH}_2\text{—}\underset{\displaystyle\text{CH}_3}{\overset{\displaystyle\text{CH}_3}{\overset{|}{\underset{|}{\text{N}}}}}\text{—R}\right)^{+} + \text{Cl}^{-}$$

共存する色素イオン（$In^-$）の濃度が界面活性剤の陽イオンより大であるときは溶液の吸光度も大である。

界面活性剤の濃度が増加するに従って，色素イオンは次第に電気的に中和されて凝析沈澱を生ずる。そのため溶液の吸光度は低下するに至る。活性剤と色素とのある濃度範囲に至ると色素は完全に沈澱し溶液の吸光度は最小値を示すようになる。

しかし，陽性界面活性剤の濃度が更に増加すると溶液中では不解離の活性剤分子，陽性イオン等が水の分子との親和力によって陽性のコロイドミセルを形成し所謂コロイド溶液となる。このコロイドミセルは色素を吸着して溶液中に分散する。それ故溶液の吸光度は増加するものと考える。この場合 Erythrosin のような色素は特に螢光を帯びる現象を示した。

著者等は寒天ゲル内に色素を固定する目的として陽性界面活性剤の濃度は色素が析出しない範囲を選択した。

そこで陽性界面活性剤 Benzalkonium Chloride による試料寒天ゲル中の色素の固定に当っては次の二つの方法を採用した。

1）陽性界面活性剤水溶液中への浸漬による固定。

色素固定用着色寒天ゲル各10個を一定濃度の Benzalkonium Chloride 水溶液に 30°C で一定時間浸漬して塩形成の測定を行った。

2）陽性界面活性剤混入による固定

オゴノリ粉末寒天1.5％，Erythrosin 0.03％ 濃度の着色寒天液を約 50°C において一定濃度の Benzalkonium Chloride を加えて放冷し寒天ゲル内に色素を固定させた。このゲルを各々 1.5 $cm^3$ に切断して，試料となし，各10個を水 100 ml に2時間浸漬して，過剰の Benzalkonium Chloride を除去した後一部はゲル10個を水 100 ml に浸漬し他の10個は更に糖度25％，pH 3.8 のクエン酸溶液のシラッ

プ 100 ml 中に入れ，80°C で20分間加熱して一昼夜放置後，水及びシラップに溶出した色素の吸光度を測定し熱処理による影響をみた。

## 結果及び考察

実験の結果は次のようである。

**1.** 硫酸アルミニウムカリウムによる色素固定の結果は第4図のようである。寒天ゲル中の色素は 0.01 M/L 硫酸アルミニウムカリウム水溶液に 30°C で 90 分間浸漬することによって固定されたが，この色素塩

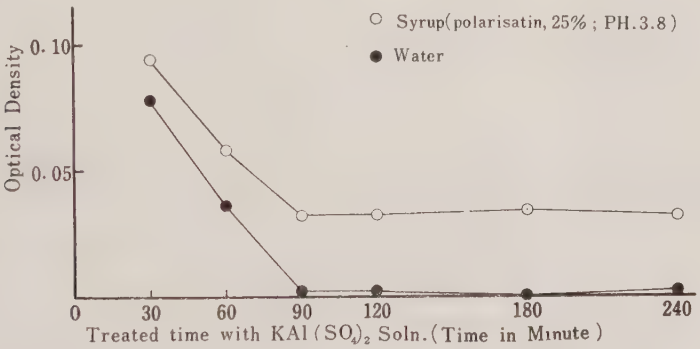


Fig. 4. Changes in absorbance (500 mμ) for soaking solution in the case of the coloured agar gels soaked in 0.01 m/1 potassium alum solution at the various hours.

は熱に弱くシラップ中では 80°C で 20 分間の加熱によって一部色素の溶出を見た。

**2.** 陽性界面活性剤水溶液中えの浸漬による色素固定の結果は第5図のようである。

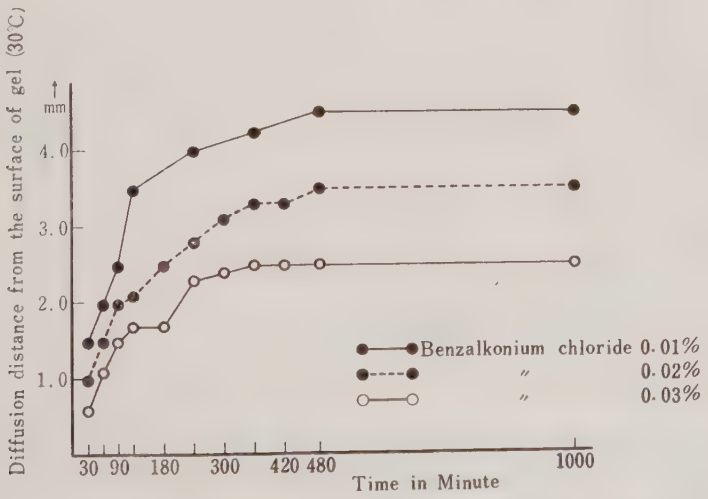


Fig. 5. Diffusion distance of cationic surface active agent in the agar gel.

寒天ゲル内えの Benzalkonium Chloride の浸透は濃度によっても異るが，試料寒天ゲル表面より一定距離以上は進行せず，これは色素塩の形成によって障壁が生じそれ以上 Benzalkonium Chloride の浸透が阻止されたものと思われる。

又この方法によって処理した着色寒天ゲルはシラップ中において，80°C で 20 分間の加熱によっても色素の溶出は見られなかった。

**3.** 陽性界面活性剤混入による色素固定の結果は第6図のようである。Benzalkonium Chloride 0.01 %

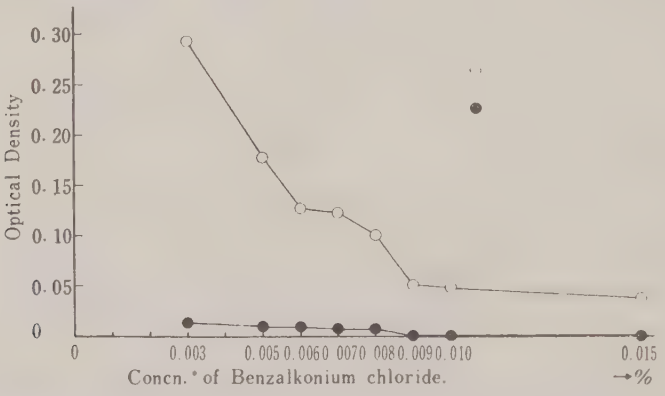


Fig. 6. Changes in absorbance (500 mμ) for soaking solution in the case of the coloured agar gels soaked in the various concentration of Benzal Konium Chloride solution.
○……Syrup, ●……water.

以上の濃度を使用した着色寒天ゲルはシラップ中えの色素の溶出が全くなく，更に加熱によっても色素の溶出を示さず強い色素塩として寒天に吸着されているものと思われた。

## 実　　験　Ⅱ

実験Ⅰの結果から得た寒天色素固定法に依って着色寒天ゲルを製造し，蜜豆罐詰固型物として5号罐に脱皮蜜柑果肉と共に混合して，真空巻締をなし殺菌加熱後，恒温器中に 30°C で 45 日間貯蔵試験を行い，この期間中に生じたラシップの吸光度，着色寒天の褪色率及びその他の変化についての比較実験を行った。

**試　　料**

試料は実験Ⅰと同じ試料を使用した。

**測 定 器 具**

1. Erythrosin の吸光度測定

着色寒天ゲルからの色素溶出度測定は実験Ⅰに準じた。

2. 糖度測定

シラップ糖度の測定は日立製作所 Hand Refractometer を使用した。

3. pH 測定

シラップ pH の測定は堀場製作所製 pH Meter M—3 を使用した。

4. ゼリー強度測定

寒天ゼリー強度の測定は日寒水式を用いた。

**試 料 調 整**

試料は次の6種類について調整し，試料に供した。

(試料 Ⅰ) 陽性界面活性剤浸漬法

オゴノリ粉末寒天1.5%，Erythrosin 0.03% 濃度で調整した寒天ゲルを各々 1.5 $cm^3$ に切断し，Benzalkonium Chloride の0.01% 水溶液に一夜（15時間）浸漬してゲル表面に色素塩を形成させた後，2時間流水洗して過剰の Benzalkonium Chloride 及び色素を除去して試料に供した。

(試料 Ⅱ) 陽性界面活性剤混入法

オゴノリ粉末寒天1.5%，Erythrosin 0.03% 濃度に調整した寒天液を50°C において，Benzalkonium Chloride を 0.01% 濃度になるよう添加して放冷しゲル化させた。それを各々 1.5 $cm^3$ に切断し，2時間流水洗して試料に供した。

(試料 Ⅲ) 硫酸アルミニウムカリウム浸漬法

オゴノリ粉末寒天1.5%，Erythrosin 0.03% 濃度に調整した寒天ゲルを各々 1.5 $cm^3$ に切断し，硫酸アルミニウムカリウムの 0.01 M/L (=0.475%) 水溶液に一夜（15時間）浸漬してアルミニウム塩をゲル内に形成した後，2時間水洗して試料に供した。

(試料 Ⅳ) 酸固定法

オゴノリ粉末寒天ゾルを 50°C においてクエン酸を加えて pH 3 として色素を固定して放冷しゲル化した。ゲルを 1.5$cm^3$ に切断し，更に pH 3 のクエン酸水溶液に浸漬したものを試料に供した。

(試料 Ⅴ) 無処理

オゴノリ粉末寒天 1.5%，Erythrosin 0.03% の寒天ゲルを 1.5 $cm^3$ に切断して試料に供した。

(試料 Ⅵ) 対照区

オゴノリ粉末寒天1.5% の無着色寒天ゲルを 1.5 $cm^3$ に切断して試料に供した。

**実 験 方 法**

蜜豆罐詰固型物として，それぞれ蜜柑罐詰用果肉（pH 3.2，糖度 10.1%）150 g Ⅰ～Ⅵの方法によって調整した寒天ゲル各 50 g 及びシラップ（糖度 45%）110 g を5号罐に入れて（最終目的糖度20% を見積って）真空巻締をなし，75°C で14分間の殺菌加熱を行い，冷水中で冷却後，30°C の恒温器中に貯蔵し，貯蔵中の 1，3，5，8，15，25，35，45日目の各試料罐詰の固型物重量，シラップ糖度，シラップ pH，寒天ゼリー強度，シラップ吸光度等を測定した。更に寒天ゲル内色素の褪色変化を測定するため，各着色試料寒天ゲル 4 g 宛をメチルアルコール 40 ml 中に浸漬し，50°C で30分間加熱し色素を抽出して冷却後抽出液の吸光度を測定し，次式に依って褪色率を算出した。

褪色率計算式

$$D\% = \frac{E_0 - E_t}{E_0} \times 100$$

D%：褪色率

$E_0$ ：最初の着色寒天ゲルの吸光度

$E_t$ ：貯蔵 t 日後の着色寒天ゲルの吸光度

## 結果及び考察

実験の結果は次のようである[3]。

1. 固型物重量

蜜柑果肉及び寒天重量の内容総量に対する百分率の変化は第7図に示した。

2. シラップ糖度

温度 20°C 換算によるシラップ糖度の変化は第8図に示した。

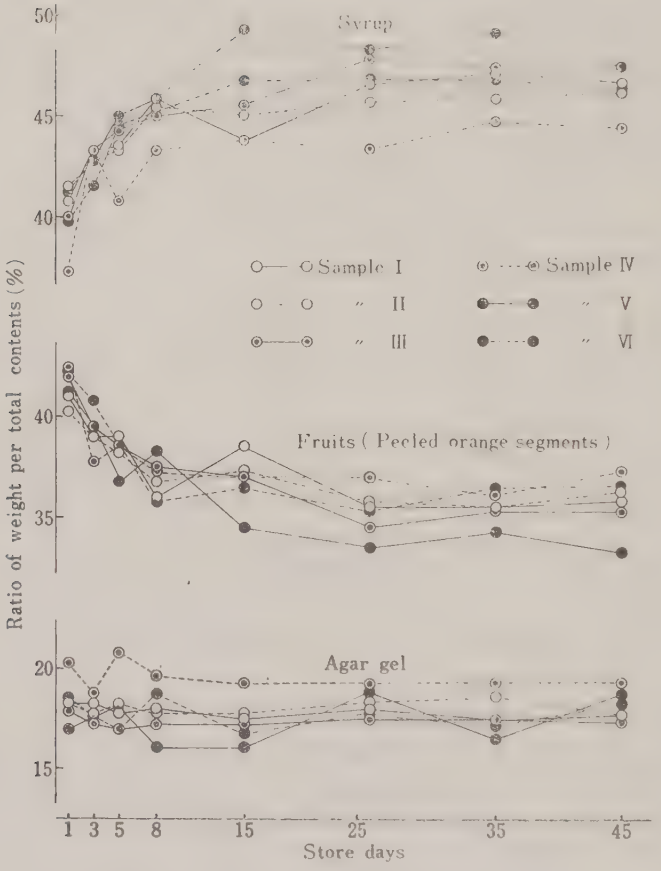


Fig. 7. Changes in weight of syrups, fruits and agar gels.

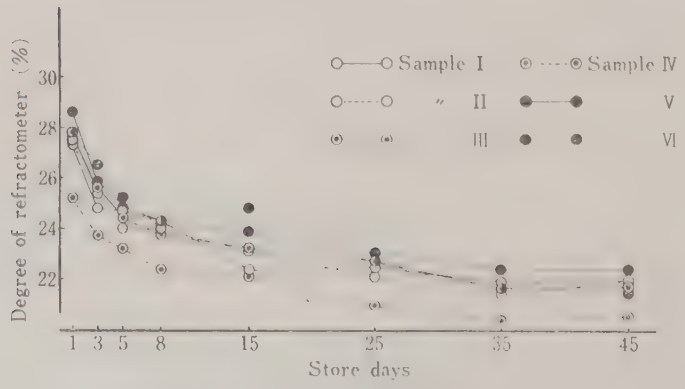


Fig. 8. Changes in percentage of sugar.

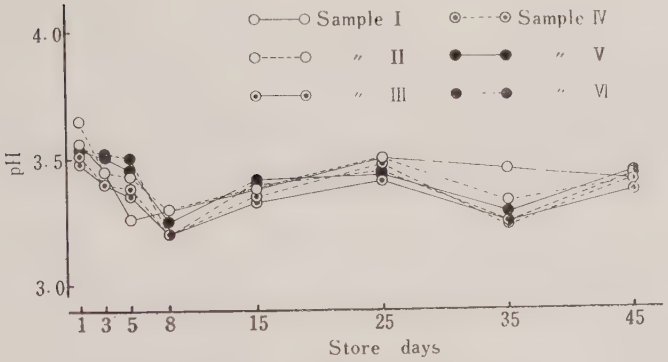


Fig. 9. Changes in pH of syrup.

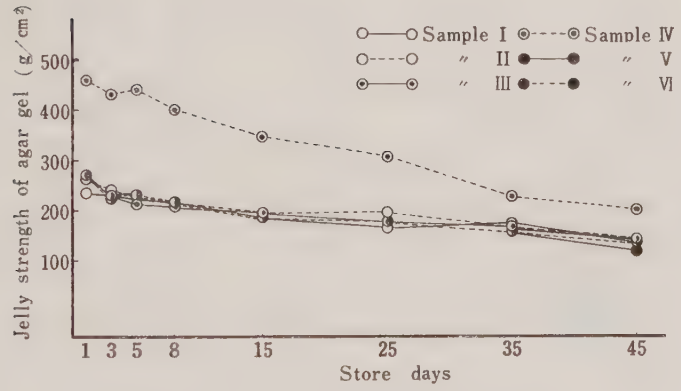


Fig. 10. Changes in jelly strength of agar gel.

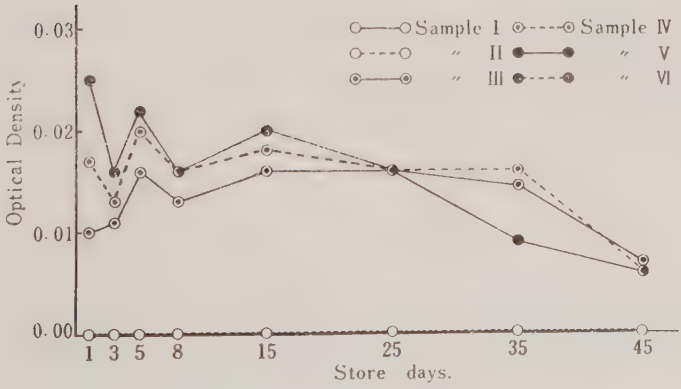


Fig. 11. Changes in absorbance (500 mμ) of syrups.

3．シラップ pH

シラップ pH の変化は第9図に示した。

4．寒天ゼリー強度

温度20°C 換算に依る寒天ゼリー強度の変化は第10図に示した。

5．シラップ吸光度

シラップ吸光度の変化は第11図のようである。陽性界面活性剤 Benzalkonium Chloride によって色素固定を行った試料Ⅰ，Ⅱにあっては，シラップ中えの色素の溶出は全然見られず，非常に良好な結果が得られた。

尚，試料Ⅲ～Ⅴにあっては，貯蔵15日目以降は日数の増加に従ってシラップの吸光度が減少してきた。これは当初シラップ中に溶出してきた寒天ゲル内の色素が二次的に蜜柑果肉の有機酸によって色素酸となってその表面に吸着されたものと考えられる。それ故シラップの吸光度の減少を示したのである。

6．寒天ゲル内色素の褪色

寒天ゲル内色素の褪色率は第12図のようである。陽性界面活性剤 Benzalkonium Chloride によって，

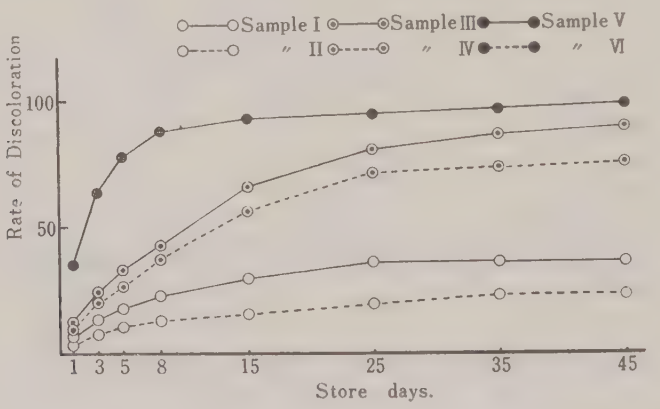


Fig. 12. Changes in the rate of discolouration of coloured agar gel.

色素固定を行った試料Ⅰ及びⅡの褪色率は極めて低く，他の色素固定法に比べても，いずれよりも非常に良好であった。特に寒天ゲル内に色素塩を分散せしめた陽性界面活性剤混入法に比べても，寒天ゲル表面に色素塩を作る陽性界面活性剤浸漬法よりも良好であった。

なお，陽性界面活性剤の人体に対する影響は通常の使用濃度（稀釈倍数 1,000～2,000）には何等考慮の必要はないといわれている[4]。本法による固定に使用する濃度は更にこれよりも遙かに稀薄であるから，何等影響はないものと考えられる。

## 要　　約

1．蜜豆罐詰用着色寒天ゲルの色素固定剤として，陽性界面活性剤，クエン酸及び硫酸アルミニウムカリウム等を使用して色素の固定を行った。

2．硫酸アルミニウムカリウムによって，寒天ゲル内に固定された色素塩は，熱に対して弱く色素の溶出を見た。

3．従来一般に広く採用されているクエン酸による色素固定法は，硫酸アルミニウムカリウムによる色素固

定法よりも良好であった。

4. 陽性界面活性剤によって固定された色素塩は，他の固定剤によったものよりも熱に対しても非常に強く，良好な結果を得た。
5. 陽性界面活性剤による色素の固定においては，寒天ゲル表面に色素塩を作る浸漬法によるよりも，寒天ゲル内に色素塩を分散せしめる陽性界面活性剤混入法によったものの方が最も良好な結果を得た。
6. 蜜豆罐詰内の着色寒天ゲルより溶出した色素は始めはシラップを染色するが，二次的に果実に吸着して着色する。そのためシラップの色調は徐々に褪色する現象を示した。

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# 油鞣法の検討(其の四)※

松　沢　定　五　郎

## Considerations on oil tanning※

By

Jogoro MATUZAWA

In this report two problems are considered as follows.

1) Soaking.

It is noted in my previous paper that soaking the oiled skin results in hightening Ts of it. In this paper some deta are obtained in more details.

a) Soaking results in hightening Ts of the oiled skin only when it is applyed to such a oiled skin as its oil agents (contained in the skin) has become non diffusable in water (see table 1).

b) Effect of soaking times in a day, or successive soaking times through the all tanning proccess are remarkable in eary stage of the process, but obscure in post (see tables 2, 3).

c) Soaking effects to Ts of the oiled skin in different degree as its tanning process differs (see table 6).

d) Soaking is seemed to more effective to such a tanning process as the loss of moisture of the oiled skin during its process is more (see table 6).

e) Two methods, namely soaking oiled skin in water and wetting oiled skin in saw dust, are compared to find the highest Ts of each (see table 7). From this deta soaking is seemed to supply not only moisture to the oiled skin but some other factors to highten Ts of it.

2) Esters.

f) Shift of Ts is affected in points of speed of tanning and the highest Ts to be attained by various esters respectively in dip tanning (see table 8).

### (1) 水　浸

前報において油皮を水浸することにより確実にその油皮の Ts を上昇せしめることを記した。この項では次の区別に従って水浸工程の効果を検討してみた。

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① 〔湿干一水浸〕法における水漬時期と回数

② 〔湿干一水浸〕法における油皮の湿潤化法

③ 漬醗法における水浸

④ 油水漬

その経過次の如し。

①（i）〔湿干一水浸〕法における水浸時期とその回数

**実　験　一**

方　法。塩干鮫皮を払鱗後鋸屑与湿して1月24日より同28日迄加油湿干（35°C 80％湿度）を反復して得た油皮を試料とした。

この試料を以て水浸の時期とその回数の効果を実験した。但し水浸時間は1回30分間とした。

成　果。第1表の通り。

Table 1. Effect of soaking times to Ts of the oiled skins

| Date / No | 24～28—Jan. | 28—Jan. | 29—Jan. | 30—Jan. | 31—Jan. | 1—Feb. | 2—Feb. |
|---|---|---|---|---|---|---|---|
| | | Ts | Times of soaking in water | Ts | | Times of soaking in water | Ts |
| 1 | Salted, dry skins are wetted in wet saw dust, Skins are oiled every day, and stored in the box which is warmed to 35°C, and wetted by about 80 % of relative moisture. | 45.5 | 4 | 46.5 | … | … | … |
| 2 | | 45.5 | 3 | 47.5 | … | … | … |
| 3 | | 45.5 | 2 | 48.5 | … | … | … |
| 4 | | 46.5 | 1 | 51.5 | … | … | … |
| 5 | | 45.5 | Stored in the box. | … | Stored in the box. | 4 | 59.5 |
| 6 | | 45.5 | | … | | 2 | 53.5 |

Skins…Salted, dry Shark skin, its original Ts＝51.5°C
Tanning oil…Sardine oil
Water for soaking the oiled skins…warmed to 35°C±2°C
All samples are tanned in the box, which is warmed to 35°C, wetted by 80 % moisture.

考　察。No. 1，2，3及び4の一群とNo. 5及び6の二群との水浸回数別 Ts の移動の方向は逆になっている。即ち一群は水浸回数の多いもの程その Ts は低く，二群では逆に高くなっている。

両群の処理品を見ると一群の含油量は総体的に少く，特に少い No. 1 の如きは折り曲げると折損した。が二群は含油量が多かった。

このことから考えて一群の水浸時期においては油剤の変化がなお充分でなくまだ遊離性であったため水浸工程において油剤は皮組織より離脱したものと，又二群の水浸時期にはその油剤は既に固着性になっていたものと考えられる。

この故に油剤が遊離性である間はその油皮の Ts は水浸工程によって上昇すると少く，固定性になって初めて上昇するものと想定される。

②の（i）〔湿干一水浸〕における水浸度数と湿潤化法

**実　験　二**

方　法。前実験において油皮の水浸は一度（1日間）の水浸回数を多く行った方がその Ts の上昇に役立つことを観察した。この項においては九度水浸回数を多くしたものと少くしたものの比較を主として行い，鋸屑与湿と対比した。

成　果。第2表の通り。

Table 2. Effect of successive soaking to Ts of the oiled skins.

| No. | 25–Jan. | | 26～31 –Jan. | 1–Feb. | | 2–Feb. | 3–Feb. | | 4–Feb. | 5–Feb. | | 6–Feb. | 7～8 –Feb. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ts | | Soaking times | Ts | | Soaking times | Ts | | Soaking times | Ts | | |
| 7 | Wetted in saw dust | 51.5 | 〔Oiling–Drying in the box〕 is repeated | Soaking in water –Drying in the box 5 | 49.5 | Drying in the box | Soaking in water –Drying in the box 5 | 51.5 | Drying in the box | Soaking in water –Drying in the box 4 | 53.5 | Oiling–Drying in the box | Drying in the box |
| 8 | | 51.5 | | 4 | 47.5 | | 4 | 51.5 | | 4 | 55.5 | | |
| 9 | | 51.5 | | 3 | 46.5 | | 3 | 51.5 | | 3 | 54.5 | | |
| 10 | | 51.5 | | 2 | 45.5 | | 2 | 50.5 | | 2 | 53.5 | | |
| 11 | | 51.5 | | 1 | 44.5 | | 1 | 52.5 | | 1 | 55.5 | | |
| 12 | | 51.5 | | Drying in the box Wetted in saw dust … | 45.5 | | Drying in the box Wetted in saw dust … | 48.5 | | Drying in the box Wetted in saw dust … | 52.5 | | |
| 13 | | 51.5 | | | 45.5 | | | 49.5 | | | 49.5 | | |
| 14 | | 51.5 | | | 52.5 | | | 50.5 | | | 49.5 | | |

| No. | 9–Feb. | | 10 –Feb. | 11–Feb. | | 12,13,14 –Feb. | 15–Feb. | | 16,17 –Feb. | 18–Feb. | | 19～22 –Feb. | 23–Feb. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Soaking times | Ts | | Soaking times | Ts | | Soaking times | Ts | | Soaking times | Ts | | Soaking times | Ts |
| 7 | Soaking in water –Drying in the box 5 | 58.5 | Oiling–Drying in the box | Soaking in water –Drying in the box 4 | 58.5 | Drying in the box | Soaking in water –Drying in the box 5 | 59.5 | Drying in the box | Soaking in water –Drying in the box 5 | 58.5 | Drying in the box | Soaking in water –Drying in the box 5 | 59.5 |
| 8 | 4 | 58.5 | | 4 | 58.5 | | 4 | 59.5 | | 4 | 59.5 | | 4 | 59.5 |
| 9 | 3 | 59.5 | | 4 | 59.5 | | 3 | 58.5 | | 3 | 58.5 | | 3 | 57.5 |
| 10 | 2 | 56.5 | | 3 | 57.5 | | 2 | 57.5 | | 2 | 57.5 | | 2 | 58.5 |
| 11 | 1 | 57.5 | | 2 | 58.5 | | 1 | 58.5 | | 1 | 57.5 | | 1 | 58.5 |
| 12 | Drying in the box Wetted in saw dust … | 54.5 | | Drying in the box Wetted in saw dust … | 52.5 | | Drying in the box Wetted in saw dust … | 54.5 | | Drying in the box Wetted in saw dust … | 53.5 | | Drying in the box Wetted in saw dust … | 53.5 |
| 13 | | 52.5 | | | 52.5 | | | 54.5 | | | 53.5 | | | 53.5 |
| 14 | | 51.5 | | | 50.5 | | | 48.5 | | | 49.5 | | | 49.5 |

All conditions of this table are the same to those of the Table 1.

考 察。No. 7, 8, 9, 10及び11の水浸群を見ると, 第1回（2月1日）の測定においては水浸回数の多い程 Ts は高くなっているが, その後の測定値を通観すると水浸回数別の Ts の移動傾向は明かでない。そしてその差は少いから水浸回数の影響は殆んどないものと考えられる。

鋸屑給湿法のもの見ると, その油皮の Ts は漸増して第6の測定（2月15日）において最高に達している。

湿干単独法は第二測定（2月1日）で最高に至っている。

各法の最高 Ts を比較すると〔湿干一水浸〕法は 59.5°C 鋸屑給湿法は 54.5°C, 湿干単独法は 52.5°C である。この成果から考えると油皮の Ts を高めるためには 80 % 前後の気中に油皮を保蔵するのみではなお水分が不足していることが想像される。

②の (ii) （i）実験の再演

**実 験 三**

方 法。(ii) 実験においては鋸屑給湿法及び湿干単独法の試料は脱塩工程を経ていない。即ち含塩のま

ま処理されたので，その Ts の上昇はこのために防げられた（前報摘要3を参照）ためにその最高 Ts は異常に低かったとも考えられるのでこの実験においてはそのことを又前実験の再現性を確めるために行った。

なお，湿干室温度は当初は 35°C 前後とし，2月17日以後は 42°C とした。

なお，本実験の2月26日以後のものは同一法によって処理し，その到達し得る最高 Ts を求めることとした。

成　果。第3表の通り。

考　察。水浸群において水浸回数と Ts の異動の傾向は前実験と同様である。

又〔湿干一水浸〕法，〔湿干一鋸屑給湿〕法及湿干単独法の三法のそれぞれ到達した最高 Ts の序列も前

Table 3. Effect of successive soaking to Ts of the oiled skins.

| No. | 1–Feb. | 2,3 –Feb. | 4–Feb. | 5–Feb. Ts | 6,7 –Feb. | 8–Feb. | 9–Feb. Ts | 10 –Feb. | 11– | 12–Feb. Soaking times | 12–Feb. Ts | 13,14 –Feb. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18 | Wetted in saw dust–Oiling–Drying in air | Oiling –Drying in air | Drying in the box | Drying in the box | Drying in the box | Drying in the box –Soaking in running water over night | … | Drying in the box–Oiling–Drying in the box | Drying in the box | 5 | 53.5 | Drying in the box |
| 19 | | | | 45.5 | | | 44.5 | | | 4 | 53.5 | |
| 20 | | | | 46.5 | | | 44.5 | | | 3 | 52.5 | |
| 21 | | | | 45.5 | | | 47.5 | | | 2 | 51.5 | |
| 22 | | | | 47.5 | | | 45.5 | | | 1 | 50.5 | |
| 23 | | | | 45.5 | | | 43.5 | | | Wetted in saw dust … | … | |
| 24 | | | | 46.5 | | | 47.5 | | | Drying in the box … | … | |
| | | | | 45.5 | | | | | | | | |

| | 15–Feb. Soaking times | 15–Feb. Ts | 16,17 | 18–Feb. Soaking times | 18–Feb. Ts | 19,20, 21– | 22–Feb. Soaking times | 22–Feb. Ts | 23,24, 25– | 26–Feb. Soaking times | 26–Feb. Ts | 27,28 –Feb. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Drying in the box–Soaking in water | 5 | 59.5 | Drying in the box | 5 | 59.5 | Drying in the box | 5 | 60.5 | Drying in the box | 5 | 60.5 | Drying in the box –Oiling–Drying in the box |
| | 4 | 59.5 | | 4 | 58.5 | | 4 | 60.5 | | 4 | 59.5 | |
| | 3 | 58.5 | | 3 | 59.5 | | 3 | 62.5 | | 3 | 61.5 | |
| | 2 | 59.5 | | 2 | 59.5 | | 2 | 60.5 | | 2 | 60.5 | |
| | 1 | 58.5 | | 1 | … | | 1 | 58.5 | | 1 | 60.5 | |
| Drying in the box … | … | … | | Wetted in saw dust … | 51.5 | | Wetted in saw dust … | 53.5 | | Wetted in saw dust … | 54.5 | … |
| | … | … | | Drying in the box … | 50.5 | | Drying in the box … | 49.5 | | Drying in the box … | 50.5 | … |

| 29–Feb. | | 1–Mar. | 2–Mar. | | 3– | 4–Mar. | | | 5,6–Feb. | 7–Mar. | | 8～14 | 15–Mar. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ts | | | Ts | | Soaking times | | Ts | | | Ts | | | Ts |
| Drying in the box –Oiling–Drying in the box | 59.5 | Drying in the box | 〃 | 62.5 | 〃 | Drying in the box–Soaking in water | 1 | 61.5 | Drying in the box | Drying in the box–Soaking in water | 60.5 | Drying in the box | Drying in the box–Soaking in water | 59.5 |
| | 61.5 | | | 61.5 | | | 1 | 64.5 | | | 63.5 | | | 61.5 |
| | 59.5 | | | 65.5 | | | 1 | 64.5 | | | 61.5 | | | 63.5 |
| | 63.5 | | | 63.5 | | | 1 | 63.5 | | | 64.5 | | | 63.5 |
| | | | | 63.5 | | | 1 | 65.5 | | | … | | | … |
| … | … | … | … | … | … | … | … | … | … | … | … | … | … | … |
| … | … | … | … | … | … | … | … | … | … | … | … | … | … | … |

実験と同様である。但し前実験の〔湿干一水浸〕法の最高 Ts は 59.5°C で本実験のそれは 65.5°C を示したのは湿干室温度が異る。即ち前者は 33°C，後者 35°C→42°C としたことに起因しているだろう。

更に，後二法によるものは流水脱塩を行たにかかわらず前実験成果とその Ts において殆んど差異を認め得ない。この点はかような少範囲（51°C～54°C）においては試料の含塩の有無はその Ts の異動に重大には影響を与えないものと考えられる。

③　漬鞣法における水浸

**実　験　四**

方　法。漬鞣法における水浸の効果を明かにするため漬鞣の条件を次のようにした。

（a）実験室内において大気中での漬鞣

（b）給湿熱せる湿干箱中においての漬鞣，この方法においては水浸せるものとせぬものに分けた。

（c）給熱せる干燥箱中においての漬鞣この方法においても水浸せるものとせぬものに分けた。

（d）給熱せる干燥箱中においての油水漬鞣

油剤及原皮は実験の三に同じ。

成　果。第4表の通り。

考　察。処理法別にその最高 Ts を列べ子と油水漬鞣給乾熱法（d）60.5，漬鞣給乾熱法（c）60.5，漬鞣大気法（a）62.5°C 漬鞣給湿熱法（c）63.5°C，漬鞣給乾熱一水浸併用法（b）66.5°C，漬鞣給湿熱一水浸併用法（b）67.5°C であって水浸法を併用せる試料の Ts は併用しないものに比べて高い。

大気中の漬鞣法の Ts が 62.5°C を示したのはこの処理時期が梅雨期で高温多湿の気象であったためで他，即ち低温干燥の時期には期待し難い成果であろう。

油水漬鞣給乾熱法によるものの Ts は意外に低かったので次の実験を行った。

④　油水漬鞣

上述の諸実験によって油鞣には水分を必要とすることが立証されている。その故に油剤と水とを同一容器内に容れ，その油剤層中に皮を置く。とその下底の水は蒸発して油剤及皮に水分を補給することが期待される。そうすれば前記各法による給湿法と略同様の鞣が予期し得るとも考えられたので，この当否を次の実験によって検討した。

Table 4. Effect of soaking in water for Dip tanning Method.

| No. | Method | 18~23 -Apr. | 24~27 | 28-Apr. | Ts | 29-Apr. ~5-May | 6- | 7-May | Ts | 8~11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 25 | Dipp tanning, in air | Dry, Salted skins are rubbed in petroleum. | Dipped in sardine oil | Desalted in running water-Dipped in the oil | 45.5 | Dipped, Dipped, in air | // | // | 45.5 | // | // |
| 26 | Dipp tanning, wet heated | | | | 43.5 | Dipped, wet heated | // | // | 51.5 | // | // |
| 27 | Dipp tanning, wet heated -Soaking | | | | 44.5 | Dipped, wet heated | Dip -Soaking | Soaking -Dip | 48.5 | Dipped, wet heated | Dip -Soaking |
| 28 | Dipp tanning, dry heated | | | | 45.5 | Dipped, dry heated | // | // | 50.5 | // | // |
| 29 | Dipp tanning, dry heated -Soaking | | | | 45.5 | Dipped, dry heated | Soaking -Dip | Soaking -Dip | 50.5 | Dipped, dry heated | Dip -Soaking |
| 30 | Dipp tanning in Oil and water | | | | 45.5 | Dipped in Oil and water, dry heated | // | // | 48.5 | // | // |

| 13-May | | Ts | 14,15 | 16- | 17-May | | Ts | 18,19 | 20- | 21-May | | Ts | 22- | 23- | 24,25 | 26- | 27-May | | Ts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| // | Soaking -Dip | ... | // | // | // | // | 48.5 | // | // | // | // | 51.5 | // | // | // | // | // | // | 51.5 |
| // | // | 55.5 | // | // | // | // | 59.5 | // | // | // | // | 61.5 | // | // | // | // | // | // | 63.5 |
| // | // | 50.5 | Dipped, wet heated | -Dip Soaking | // | Soaking -Dip | 56.5 | Dipped, wet heated | Dip -Soaking | // | Soaking -Dip | 62.5 | Dipped, wet heated | Dip-Soaking -Dip | Dipped, wet heated | Dip -Soaking | // | Soaking -Dip | 64.5 |
| // | // | 56.5 | // | // | // | // | 58.5 | // | // | // | // | 56.5 | // | // | // | // | // | // | 60.5 |
| // | Soaking -Dip | 56.5 | Dipped, dry heated | -Dip Soaking | // | Soaking -Dip | 60.5 | Dipped, dry heated | Dip -Soaking | // | Soaking -Dip | 63.5 | Dipped, dry heated | Dip-Soaking -Dip | Dipded, dry heated | Dip -Soaking | // | Soaking -Dip | 63.5 |
| // | // | 53.5 | // | // | // | // | 54.5 | // | // | // | // | 55.5 | // | // | // | // | // | // | 60.5 |

| 28,29 | 30– | 31– | 1–Jnue | –2 | 3– | 4—June | | 5,6– | 7– | 8,9– | 10– | 11–June | | 12,13,14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Ts | | | | | | Ts | |
| 〃 Dipped, dry heated | 〃 Dipped, wet heated | 〃 | 〃 | 〃 | 〃 | 〃 | 54.5 | 〃 | 〃 | 〃 | 〃 | 〃 | 56.5 | 〃 |
| 〃 Dip–Soak –Dip | 〃 Dip–Soak –Dip | 〃 | 〃 | 〃 | 〃 | 〃 | … | 〃 | 〃 | 〃 | 〃 | 〃 | 62.5 | 〃 |
| 〃 Dipped, dry heated | 〃 Dipped, wet heated | 〃 | 〃 | 〃 | 〃 | Soaking –Dip | 65.5 | Dipped, wet heated | Dip– Soak–Dip | Dipped, wet heated | Dip– Soaking | Soaking –Dip | 66.5 | Dipped, wet heated |
| 〃 Dip– Soak–Dip | 〃 Dip– Soak–Dip | 〃 | 〃 | 〃 | 〃 | 〃 | 60.5 | 〃 | 〃 | 〃 | 〃 | 〃 | 59.5 | 〃 |
| 〃 Dipped, dry heated | 〃 Dipped, dry heated | 〃 | 〃 | 〃 | 〃 | Soaking –Dip | 65.5 | Dipped, dry heated | Dip– Soak–Dip | Dipped, dry heated | Dip– Soaking | Soaking –Dip | 65.5 | Dipped, dry heated |
| 〃 Dip– Soaking | 〃 Dip– Soaking | 〃 | 〃 | 〃 | 〃 | 〃 | 60.5 | 〃 | 〃 | 〃 | 〃 | 〃 | 61.5 | 〃 |

| 15– | 16– | 17– | 18–June | | 19,20,21– | 22– | 23– | 24– | 25–June | | 26,27,28– | 29– | 30– | 1–Jnly |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Ts | | | | | | Ts | | | | |
| 〃 Dip–Soak –Dip | 〃 | 〃 | 〃 | 57.5 | 〃 | 〃 | 〃 | 〃 | 〃 | 58.5 | 〃 | 〃 | 〃 | 〃 |
| 〃 Dipped, dry heated | 〃 Dipped wet heated | 〃 | 〃 | 60.5 | 〃 | | 〃 | 〃 | 〃 | 58.5 | 〃 | 〃 | 〃 | |
| 〃 Dip–Soak | 〃 Dip–Soak | 〃 | 〃 Soak–Dip | 67.5 | 〃 Dipped, wet heated | 〃 Dip– Soak–Dip | 〃 Dipped, wet heated | 〃 Dip–Soak | 〃 Soak–Dip | 67.5 | 〃 Dipped, wet heated | 〃 Dip– Soak–Dip | 〃 Dipped, wet heated | 〃 Dip–Soak |
| 〃 Soak–Dip | 〃 Soak–Dip | 〃 | 〃 | 60.5 | 〃 | 〃 | 〃 | 〃 | 〃 | 60.5 | 〃 | 〃 | 〃 | |
| 〃 Dipped, dry heated | 〃 Dipped, dry heated | 〃 | 〃 | 65.5 | 〃 | 〃 | 〃 | 〃 | 〃 | 66.5 | 〃 | 〃 | 〃 | |
| 〃 Dip– Soak–Dip | 〃 Dip– Soak–Dip | 〃 | 〃 | 60.5 | 〃 | 〃 | 〃 | 〃 | 〃 | 60.5 | 〃 | 〃 | 〃 | |
| 〃 Dipped, dry heated | 〃 Dipped, dry heated | 〃 | 〃 | | 〃 | 〃 | 〃 | 〃 | 〃 | | 〃 | 〃 | 〃 | |
| 〃 Dip–Soak | 〃 Dip–Soak | 〃 | 〃 | | 〃 | 〃 | 〃 | 〃 | 〃 | | 〃 | 〃 | 〃 | |

| 2–July | | 3,4,5– | 6– | 7– | 8– | 9–July | | 10,11,12, 13,14–July | 15– | 16–July | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ts | | | | | | Ts | | | | Ts |
| 〃 | 62.5 | 〃 | 〃 | 〃 | 〃 | 〃 | 62.5 | 〃 | 〃 | 〃 | 61.5 |
| 〃 | 58.5 | 〃 | 〃 | 〃 | 〃 | 〃 | 57.5 | 〃 | 〃 | 〃 | 57.5 |
| Soak-Dip | 67.5 | Dipped, wet heated | Dip–Soak-Dip | Dipped, wet heated | Dip–Soak | Soak-Dip | 67.5 | Dipped, wet heated | Dip–Soak | Soak-Dip | 67.5 |
| 〃 | 59.5 | 〃 | 〃 | 〃 | 〃 | 〃 | 60.5 | 〃 | 〃 | 〃 | 60.5 |
| Soak-Dip | 65.5 | Dipped, dry heated | Dip–Soak-Dip | Dipped, dry heated | Dip–Soak | Soak-Dip | 64.5 | Dipped, dry heated | Dip–Soak | Soak-Dip | 64.5 |
| 〃 | 61.5 | 〃 | 〃 | 〃 | 〃 | 〃 | 60.5 | 〃 | 〃 | 〃 | 60.5 |

**実 験 五**

方 法。塩干皮をイワシ油中で揉み充分油の滲透した油皮を作った。

300 cc 容ビーカー中に水道水 40 cc, 油剤 160 cc を容れ, 油皮を油層に浸し, 比較的その層の上部に吊した。硝子板をビーカーに載せて蔽とした。

それを所定のところ, 即ち大気中, 乾熱中及湿熱中に置いて, その試料の Ts を経日的に観測した。

成 果。第 5 表の通り。

Table 5. Dip tanning in Oil and water.

| No. | Oil agent | Original Ts | Ts of the samples | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 8–Apr. | 15–Apr. | 22– | 7–May | 9– | 13– | 17– | 18– | 27– | 11–June | 24– | 9–July | 16–July |
| 31 | Sardine oil (Wet heated→Dry heated) | 51.5 | Samples are hung in oil, wet heated to 32°C±2°C. | 41.5 | 38.5 | 46.5 | Desalted in running water | 49.5 | 51.5 | Dry heated to 45°C±4°C | 62.5 | 64.5 | 66.5 | 66.5 | 67.5 |
| 32 | Sardine oil (Wet heated only) | 51.5 | | 43.5 | 49.5 | 58.5 | | 61.5 | 60.5 | Wet heated to 45°C±3°C | 67.5 | 69.5 | 69.5 | 69.5 | 68.5 |
| 33 | Sardine oil, air blown (Wet heated only) | 51.5 | | 50.5 | 52.5 | 51.5 | | 52.5 | 54.5 | | 56.5 | 57.5 | … | … | … |
| 34 | Sardine oil (In air) | 51.5 | | 47.5 | 43.5 | 43.5 | | 44.5 | 49.5 | | 54.5 | 57.5 | 58.5 | 63.5 | 61.5 |

Skins…Salted dry shark skin

Samples(skins)are supported in oil layer which is contained in a beaker with water.

考　察。本実験には水浸工程は全く併用されていない。しかも最高 Ts は 69.5°C に達している。このことが先づ注目される。その次は湿熱の最高が 69.5°C で乾熱のそれが 67.5°C でその差が少いことである。

前実験第4表の No. 30 の油水漬の最高 Ts は 60.5°C 本実験中の該当試料 No. 31 のそれは 67.5°C でその間大差がある。これは鞣中の温度とその期間の長さに基因があるものと思われる。

**総 合 考 察**

如上の成果を綜合して考察すると次の通り。

1）水浸工程は油皮中の油剤が水浸に対して固定性になった以後において効果を現わす。

2）水浸回数は一度（或は一日）の回数を1～5回又9度迄断続施行したが鞣の初期においては明かに効果が認められたが，後期においては回数或は度数効果は不明である。換言すればその数の多少は問題にならないと考えられる。

3）鞣法（油剤と皮との接触方法）別に水浸効果を比較すると次のようになる。

Table 6. Summary

| Tanning method | Ts, highest | Difference (°C) | Original table |
|---|---|---|---|
| Drying in wet warm air–Soaking in water | 59.5 | 8 | Table 2 |
| Drying in wet warm air, only | 51.5 | | |
| Drying in dry warm air–Soaking in water | 61.5 | 11 | Table 3 |
| Drying in dry warm air, only | 50.5 | | |
| Dip tanning, wet heated–Soaking in water | 67.5 | 4 | Table 4 |
| Dip tanning, wet heated, only | 63.5 | | |
| Dip tanning, dry heated–Soaking in water | 66.5 | 6 | |
| Dip tanning, dry heated, only | 60.5 | | |

水浸工程を併用するかせぬかによって乾熱乾燥法においては最高 Ts の差が 11°C，湿熱乾燥法では 8°C，浸鞣乾熱法では 6°C，漬鞣湿熱法では 4°C の差が示されている。

これらの各鞣法における油皮の乾燥速度を常識的に見ると上記の序列で遅くなる。この観点からすると油皮の乾燥速度の早い鞣法における程水浸の効果は大となるといえよう。

4）水浸の効果は油皮を水中に浸すことによってのみ期待し得るものか，或は単に水分を保有せしめればよいのかを検討した。即ち単に水分を保有せしめる方法として濡れ鋸屑与湿を選んでこれを水浸法と比較した。この結果は次の通り。

Table 7. Moistening method.

| Tanning method | Moistened by | Ts, highest | |
|---|---|---|---|
| | | (Table 2) | (Table 3) |
| Drying in wet air, only | ... | 51.5 | 50.5 |
| Drying in wet air–Soaking in water | Warm water | 59.5 | 60.5 |
| Drying in wet air–Wetting in saw dust | Wet saw dust | 54.5 | 54.5 |

この表における最高 Ts の順から見ると，鋸鞣与湿法は湿干単独法より少し勝れているが，しかし，水浸法に対しては甚しく劣っている。

この数値の差から見ると水浸工程の効果は単に油皮に水分を補給することにのみにあるとは考え難い。

### （2）機　能　度

脂肪酸は機能度説によると diester は直線的に tetraster は立体的に重合するという。かような重合様式のものが油皮の鞣化にどんな関係があるかを実験して見た。

**実　験　六**

方　法。いわし油より常法によって混合脂肪酸を作る。これを材料として常法（但し無触媒）により各種 Ester を作り過剰脂肪酸は除去した。

Monoester は $CH_3OH$, diester は ethylene glycol, triester としてはいわし油そのままを tetraester は pentaerythritol を採用した。

各 ester 共灯油で 3 倍に稀釈して油剤とした。

共試皮は塩干サメ皮を払鱗後一夜間流水脱塩した後，灯油漬一揉一乾燥の三工程を繰返して柔軟な乾皮を作りこれを使用した。

接触条件（鞣法）は漬鞣給湿熱としその温度は初期 35°C±2°C，中後期 40°C±2°C とし，全期間に亘り湿度は 80～85 % とした。

成　果。第 8 表の通り。

Table 8. Ts for various esters respectively.

| No. | Esters | 12–Oct. | 14– | 17– | 19– | 21– | 24– | 26– | 28– | 31– | 2–Nov. | 4– | 7– | 9– | 11– | 14– | 16– | 18– |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ts of the oiled skin (°C) | | | | | | | | | | | | | | | | |
| 32 | Monoester | 49.5 | 50.5 | 56.5 | 60.5 | 62.5 | 66.5 | 66.5 | 67.5 | 66.5 | 70.5 | 72.5 | 74.5 | 74.5 | 74.5 | … | … | … |
| 33 | Diester | 48.5 | 49.5 | 54.5 | 54.5 | 55.5 | 57.5 | 58.5 | 59.5 | 61.5 | 62.5 | 62.5 | 62.5 | 65.5 | 64.5 | 63.5 | 63.5 | 63.5 |
| 34 | Triester | 50.5 | 46.5 | 47.5 | 46.5 | 50.5 | 51.5 | 54.5 | 54.5 | 55.5 | 58.5 | 56.5 | 57.5 | 57.5 | 60.5 | 62.5 | 62.5 | 62.5 |
| 35 | Tetraester | 49.5 | 50.5 | 56.5 | 55.5 | 56.5 | 57.5* | 57.5 | 55.5 | 56.5 | 57.5 | 57.5 | 57.5 | 56.5 | 57.5 | 56.5 | 57.5 | 57.5 |
| 36 | Fatty acids | 48.5 | 45.5 | 53.5 | 53.5 | 54.5 | 56.5 | 57.5 | 59.5* | 59.5 | 59.5 | 59.5 | 60.5 | 61.5 | 63.5 | 64.5 | 63.5 | 64.5 |

All esters are diluted by pelroteum to 3 times by in volume
Skins…Shark skin, softened by petrokum and dried.

考　察。到達し得た Ester 別最高 Ts を見ると，

monoester—74.5°C，diester—65.5°C，mixed fatty acids—64.5°C，triester—62.5°C，tetraester—57.5°C の順になっている。

Ts の上昇速度を見るとその序列は大体上記の通りであるが，tetraester は当初 monoester と同速度で上昇したが，油剤に沈澱が認められた前後よりその上昇はなくなった。混合脂肪酸は沈澱の生成の始まった頃その上昇は一度停止したが，その後又上昇を始めた。このことは前者においては有効成分全部が沈澱したか或いは不活性に後者においてその一部がそのようになった結果と想像される。従ってこれら油剤の鞣皮性は本法の条件とは別のもので実験して見なければその全体が明かでないと考えられる。

唯，monoester がその中に単に皮を漬けて静置するだけで 20 数度 Ts を上昇せしめたことは注目される。

## 摘　　要

油鞣法における C 程中水浸法とその油剤としての脂肪酸エステルに付若干の検討を行って次の結果を得た。

水浸法においては

1）湿干一水浸法にあっては油皮中の油剤が水に対し固定性となった以後に水浸するとその Ts 上昇に効果がある。がその油剤が水中で游離するような時期に行うとその効果はない。

2）又この法による鞣製の初期においては水浸回数の多い方が効果は多い。その後期においては回数は多くても少くともその上昇度は変らない。勿論全く水浸せぬものと比べると到達する最高 Ts は甚しく高い。

3）水浸工程の効果は鞣製法別に異る。即ち油皮乾熱法では 11°C，同湿熱法では 8°C，漬鞣乾熱法は 6°C，同湿熱法では 4°C を水浸 C 程併用によって上昇する結果が見られた。即ち比較的乾燥状態にある製法において水漬効果は大であるようである。

4）油皮を湿潤化する方法として，油皮を水浸する法と油皮を濡鋸鞣中に埋めて湿潤せしめ方法と比較した。前法がより有効であった。このことから水浸は単に水分を補給だけでなく，その以外に Ts 上昇の原因を作ることが予想される。

機能度の実験においては

5）いわし油脂肪酸から $CH_3OH$, Ethylene glycol，及び pentaerythol で Ester を作りその性能を観測した。ester 別最高 Ts のモノエステル 74.5°C，ヂエステル 65.5°C 混合脂肪酸 64.5°C，いわし油，62.5°C，テトラエステル 57.5°C であった。

この値は漬鞣湿熱法によったものであり，他に適当な鞣化方法あり，それによれば異る結果が得られるかも知れない。

## 文　　献

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# ベンガル湾冬季における浮游性珪藻の分布について※

鶴　田　新　生

## On the Distribution of Pelagic Diatoms during the Winter at Bengaru Bay※

By

Arao TSURUTA

In the previous works (3)~(5) of the author dealing with the oceanographical and planktological studies in the Indian Ocean, the investigations referred to the tuna fishing ground on the area across the nothern Indian Ocean from the middle to east.

Present report is concerned with the occurrence and distribution of the pelagic diatoms of trawling or tuna fishing ground at the area across the Bengaru Bay from the east to west. The results deal with in the area mentioned were based on the investigation made during 1956—'57 winter cruise of our training and reaearch vessel "SHUNKOTSU-MARU".

In the occurrence of pelagic diatoms during winter at Bengaru Bay there are quite different in qualities between the middle and the coastal area of this waters. In the middle area the oceanic diatoms are occurred dominantly: *Planktoniella sol, Chaetoceros coarctatus, Cheto. peruvianus, Thalassiothrix longissima, Rhizosolenia stylformis,* etc.

We find, however, in the costal area, remarkably large volume of neritic diatoms such as *Chaetoceros compressus, Chaeto. Lorenzianus, Chaeto. pelagicus, Biddulphia sinensis, Bacteriastrum varianus, Thalassionema nitzschioides, Tahlassiothrix Frauenfeldii, Nitzschia seriata.*

We meet with large qualities of diatoms chiefly in the area north and east of the Bay: diatoms-rich area appears to extend between the mouths of Gangis and Irawagi River.

Concluding the main features of pelagic diatoms distrubution in the Bengaru Bay,

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according to the present investigation of the "SHUNKOTSU-MARU", we may note that an area showing remarkably large quantities of the neritic diatoms, was found on the eastern side of the Bay on the cost of the Peninsula Biruma and Marai (D, st. 25～29).

Besides, oceanic diatoms contributed the great mass on the west side of Andaman Is. of the middle part of the Bay (B, st. 1～15, 18～20). At the western part of Nicobaru Is. (A, st. 2～6), the northern and western part of the west of the Bay (C, and E, st. 16～17, 21～24), we find on the whole quite considerable mixed quantities of both oceanic and neritic diatoms.

## I 緒 言

本所の練習船俊鶻丸は1953年より印度洋において鮪漁場の調査を実施してきた。その際採集されたプランクトンについては研究の結果をそれぞれ発表した。[3)4)5)] 更に俊鶻丸は'57年11月から翌'58年2月に亘る期間，ベンガル湾でトロール並びに鮪漁場の調査を行った。その折採集されたプランクトン標品中特に珪藻類についてそれ等の組成並びに分布状況を調査したので茲に報告する。本文を草するに当り，海洋観測及び生物の調査採集に従事され貴重な資料標品を提供された本所綱尾晴氏，並びに御助言賜った千葉卓夫教授，御援助頂いた桂木健君に対し深謝の意を表する。

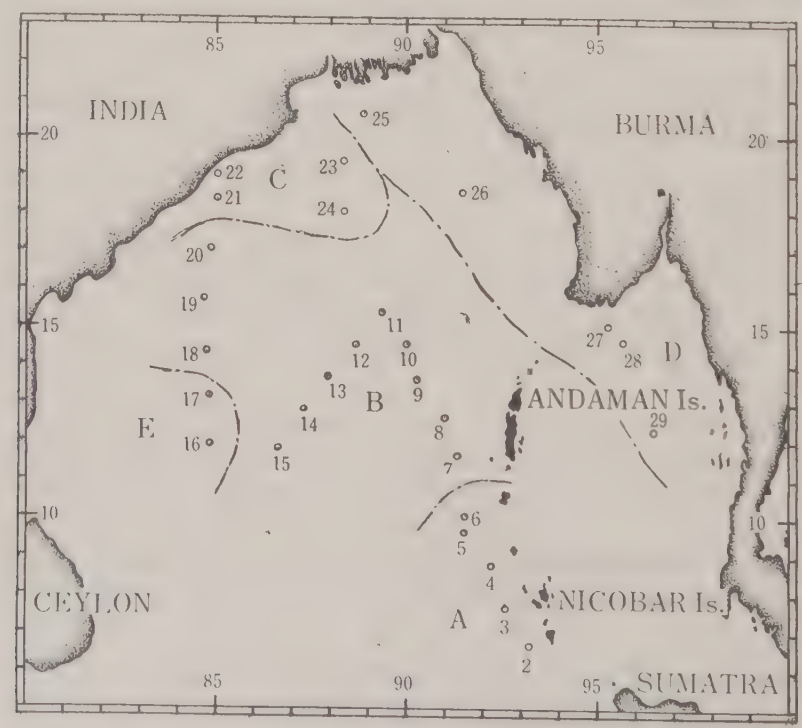


Fig. 1. Map showing the collecting stations at Bengaru Bay.

## Ⅱ 海況とプランクトン沈澱量

調査は'57年12月24日より'58年1月20日に亘り第1図第1表に示す通り，ベンガル湾の29点で行われた。使用したプランクトンネットは口経45 cm 長さ 1 m，日本製篩絹 XX 13 の中井式のもので，浅海を除いて通常水深 100 m より水面まで毎秒 50 cm の速さで垂直的に引上げ採集した。プランクトンの沈澱量は大型プランクトン（毛顎類・甲殻類・皮嚢類・多毛類・水母等）を除去し，沈澱管に移し 24 時間静置後測定したものであるが，その結果は第1表に示した。即ち沈澱量の多かったのはベンガル湾北部から東部にかけての沿岸海域であり，次いでニコバル群島西方海域であった。アンダマン群島西方海域から湾の中央，北西部沿岸にかけての海域では少ない傾向が認められた。

Table 1. Investigation period and hydrographic conditions.

| St. | Locality | | Date (1957～'58) | Time | Collecting depth(m) | Water colour | Transparency (m) | Deposited of PL. (cc) | Water temperature (°C) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lat. (N) | Long. (E) | | h m | | | | | 0 m | 50 m | 100 m | 150 m |
| 2 | 6°41′05″ | 93°12′00″ | Dec. 24 | 22 30 | 100→0 | — | — | 1.1 | 28.30 | 28.19 | 22.32 | 17.31 |
| 3 | 7°42′00″ | 92°37′05″ | 25 | 07 15 | 〃 | 3 | 23 | 1.8 | 27.90 | 27.78 | 21.60 | 14.67 |
| 4 | 8°48′50″ | 92°10′00″ | 25 | 22 00 | 〃 | — | — | 2.7 | 27.55 | 27.16 | 27.06 | 15.39 |
| 5 | 9°39′00″ | 91°30′00″ | 26 | 07 30 | 〃 | 2 | 24 | 1.7 | 27.95 | 28.04 | 23.56 | 16.55 |
| 6 | 10°04′05″ | 91°34′05″ | 26 | 22 00 | 〃 | — | — | 2.8 | 28.05 | — | 24.16 | 16.82 |
| 7 | 11°46′00″ | 91°21′00° | 27 | 07 40 | 〃 | 3 | 24 | 0.9 | 28.05 | — | 25.11 | 17.38 |
| 8 | 12°41′00″ | 91°00′05″ | 72 | 21 52 | 〃 | — | — | 1.5 | 28.05 | 28.42 | 22.58 | 17.17 |
| 9 | 13°41′00″ | 90°22′05″ | 28 | 07 45 | 〃 | 3 | 22 | 1.5 | 27.75 | 26.48 | 24.22 | 15.79 |
| 10 | 14°35′00″ | 90°02′00″ | 28 | 20 00 | 〃 | — | — | 1.4 | 27.05 | 28.10 | 23.31 | 18.93 |
| 11 | 15°25′05″ | 89°25′00″ | 29 | 08 00 | 〃 | 2 | 28 | 0.7 | 27.15 | 26.47 | 22.31 | 51.57 |
| 12 | 14°33′00″ | 88°44′00″ | 29 | 22 15 | 〃 | — | — | 1.7 | 26.38 | 28.11 | 23.94 | 18.93 |
| 13 | 13°36′00″ | 87°59′00″ | 30 | 08 30 | 〃 | 3 | 22 | 1.4 | 27.31 | 26.47 | 17.57 | 10.73 |
| 14 | 12°49′00″ | 87°19′00″ | 30 | 21 45 | 〃 | — | — | 2.2 | 27.26 | 26.80 | 21.61 | 18.65 |
| 15 | 11°49′05″ | 86°37′02″ | 31 | 08 20 | 50→0 | 3 | 22 | 1.3 | 26.96 | 27.51 | 22.18 | 18.09 |
| 16 | 11°55′00″ | 84°55′00″ | Jan. 1 | 00 25 | 100→0 | — | — | 1.5 | 26.57 | 27.60 | 21.95 | 18.73 |
| 17 | 13°12′15″ | 84°53′00″ | 1 | 10 45 | 〃 | 2 | 27 | 1.9 | 26.86 | 27.35 | 21.67 | 18.57 |
| 18 | 14°27′05″ | 84°46′00″ | 1 | 20 00 | 〃 | — | — | 0.4 | 26.27 | 26.85 | 22.38 | 18.27 |
| 19 | 15°46′00″ | 84°46′00″ | 2 | 05 10 | 〃 | — | — | 0.6 | 27.45 | 26.75 | 21.71 | 16.44 |
| 20 | 17°08′00″ | 84°51′00″ | 2 | 14 30 | 〃 | 3 | 32 | 2.0 | 27.45 | 26.89 | 23.43 | 18.05 |
| 21 | 18°18′05″ | 85°00′00″ | 2 | 22 55 | 〃 | — | — | 1.6 | 26.51 | 27.31 | 22.45 | 17.13 |
| 22 | 19°03′00″ | 85°03′00″ | 3 | 05 55 | 50→0 | 3 | 23 | 1.1 | 25.97 | 26.16 | — | — |
| 23 | 19°22′00″ | 88°23′00″ | 13 | 19 18 | 100→0 | — | — | 1.5 | 27.15 | 26.90 | 22.64 | 17.72 |
| 24 | 18°03′05″ | 88°22′00″ | 14 | 07 45 | 〃 | 2 | 22 | 1.0 | 26.16 | 26.67 | 23.59 | 18.89 |
| 25 | 20°44′05″ | 88°54′05″ | 15 | 07 45 | 80→0 | 5 | 17 | 3.9 | 25.00 | 26.19 | 22.41 | — |
| 26 | 18°33′00″ | 91°28′00″ | 16 | 17 35 | 100→0 | 3 | 24 | 1.5 | 26.66 | 26.54 | 23.23 | 15.43 |
| 27 | 15°09′05″ | 95°18′00″ | 18 | 04 45 | 30→0 | 6 | 13 | 16.9 | 27.35 | 25.65 | — | — |
| 28 | 14°40′00″ | 95°37′00″ | 19 | 08 30 | 100→0 | 4 | 21 | 5.5 | 26.36 | 25.30 | 19.78 | — |
| 29 | 12°18′00″ | 96°26′00″ | 20 | 01 15 | 〃 | — | — | 3.3 | 27.95 | 26.73 | 19.81 | — |

Table 2. Occurrence of the diatoms.

| Species name | Station No. | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| *Coscinodiscus* | *excentricus* | | | | | | | R R | R R | |
| | *lineatus* | R R | R R | | R R | | | | | |
| | *radiatus* | | R R | | | | | | R R | R R |
| | *subtilis* | | | | | R R | | | | |
| | *Granii* | | | | | | | | | |
| | *centraris* | R R | | | | | R R | | | |
| | *asteromphalus* | | | | | | | | | |
| | *gigas* | | | R R | | | | R R | | |
| | *Janischii* | | | R R | | | | | | |
| | *nobilis* | | | | | | | | | |
| *Planktoniella* | *sol* | C | R | R R | R R | R | C C | C | C C | C C |
| *Asterolampra* | *marylandica* | | | | | | | | | |
| | *hepaticus* | | | | | | R R | | | |
| | *Grevillei* | | | | | | | | | |
| *Gossleriella* | *tropica* | | R | R R | R R | R R | R | R | R | |
| *Lauderia* | *borealis* | | | | | R R | | | R R | |
| *Schrödella* | *delicatula* | R | | | R | | | | | |
| *Skeletonema* | *costatum* | R | | R R | | | | | | |
| *Stephanopyxis* | *Palmeriana* | + | | + | | + | R R | R R | | |
| *Dactyliosolen* | *tenuis* | | | | | | | R R | R R | + |
| *Leptocylindrus* | *danicus* | | | | R | R R | | R R | | |
| | *adriaticus* | | | | R | R R | | R R | | |
| *Guinardia* | *flaccida* | R | | | | | | | | |
| | *Blavyana* | | | | | | | | | |
| *Rhizosolenia* | *alata* | C C | C C | C C | C C | C C | C C | C C | C | C C |
| | *alata* fo. *gracillima* | R R | R R | | R | + | | | R R | R R |
| | *alata* fo. *indica* | | R R | | | | | | | |
| | *fragilissima* | R | R R | | R R | + | | | | |
| | *stolterfothii* | | R R | | R R | + | | | | R R |
| | *cylindrus* | | | | | | | | | R R |
| | *robusta* | | R R | C | | + | R R | + | | |
| | *imbricata* | | | | | | | | | |
| | *setigera* | | R R | | | R | | R R | | |
| | *styliformis* | R | C C | | R | C C | R | R R | R R | + |
| | *styliformis* var. *latissima* | + | C | C | C | C | R | R | | C C |
| | *calcar-avis* | | R | R R | R R | C | R R | R R | | R |
| | *hebetta* fo. *semispina* | C | C | | R R | R | R R | | R | |
| | *acuminata* | R R | | | | R | | | | |
| | *Bergonii* | R | R R | + | + | R | R | R | R R | R R |
| | *Castracanei* | | | R | | R R | R R | R R | R R | + |
| | *arafrensis?* | | | | | | | | | |
| *Bacteriastrum* | *varians* | C | | R | R R | | | R R | | R R |
| | *hyalinum* var. *princeps* | | | | | | | | | |
| | *delicatulum* | | | | | | | | | |
| | *comosum* | | | | R R | | | | | |
| | *minus* | | | | | | | | | |

| 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R R | | | | | R R | | | | R R | | | | | | | | | |
| | | R R | | | | | | | | R R | | R R | | | | | | |
| | | | | | | | | | | | | | | | | | | R R |
| | R R | R R | | | | | | | | R R | R R | R R | | + | R R | | | |
| | | R R | | | | | | | | | | | R R | R R | | R R | R R | R R |
| | | | | | | | | | | R R | R R | | R R | + | | R R | R R | |
| | | | | | | | | | | R R | | | | R | | | | |
| C C | C C | C C | C | C | C C | C | + | C C | C | C C | + | C | C C | R R | + | | R R | C |
| | | R R | | | | | | | | R R | | R R | | | | | | |
| R R | R R | | R R | | | | | | | | | | | | | | | |
| + | R R | R | R R | R R | R | R R | | | | | | R R | R R | | R R | | | R R |
| | | | | | | | | | | | | | | | | R R | | |
| | | | | | R R | | | | | | | | R R | R | R R | R | R | R R |
| | | | | | R R | R R | | | | | | | | R R | + | C | + | |
| | | | | | | | | | | | | R R | | R R | | | | |
| R | R R | R | R R | R R | | R | R | R R | R R | | R R | | | R R | R R | | R R | R R |
| | | | | | | | | | | | | | | R R | | | | |
| | | | | | | | | | | | R R | R R | | | | | | |
| + | + | R | C | C C | R | R | R | R R | + | | R R | C | + | C C | + | R R | + | C |
| | | R R | + | R | R R | R | + | | | | | R | R R | R R | R R | | R R | |
| | | | | | | | | | | | | R R | | R R | | | | |
| | | | | | R R | | | | | | | | | R | R R | + | R | |
| | | | | | | | | | R R | R R | R R | | R R | R R | R R | R R | R | |
| | | | | R R | | | | | R R | | | | | R R | R R | R R | R | |
| | | | | | R R | | | | R R | | | | | | | | | |
| | | R R | | | | | | | | | | | | R R | | | | |
| | | | | | R R | | | | | | | R R | | + | R R | R R | R | |
| R | C C | C | C C | C | + | C C | C C | C | C | + | + | R | + | R | R R | R R | R | R |
| R | R | | R | + | | R R | | R | R | R | | R R | + | + | R R | R R | + | + |
| | | R | | + | + | R | | | + | R R | R R | R R | + | C | + | + | + | + |
| C | | C | | R | | C C | C | R R | + | | | | C | + | R R | + | C | C C |
| R R | | R R | | R R | | | R R | R | R R | | | R R | | | | | | |
| R | R | | | + | + | R | | | | R R | | | | | | | R R | + |
| R R | R | | | R R | | R R | | R | R | R | R R | R R | R | R R | | R R | R R | R R |
| | | | | | | | | | | | | | R R | | | | | |
| R R | | | | | R | + | | | R R | R | R | | | C | C | C C | C C | |
| | | | | | | | | | | | | | | R | | R | | |
| | | | | R | | | | | | | | | | | | | | |
| | | | | | | | | R R | | | | | | R R | R | | | |
| | | | | | | | | | R R | | | | | | | | | |

| Species name \ Station No. | | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| | *elegans* | | | | | | | | | |
| *Chaetoceros* | *atlanticus* | | | | R | R R | | R R | | |
| | *coarctatus* | | R | C | + | + | + | ++ | R R | + |
| | *tetrostichon* | | | | | | | | | |
| | *denticulatum* | | | | | | | | | |
| | *indicum* | | | | | | | | R R | |
| | *peruvianus* | | | | R R | R | | R | R | R R |
| | *pendulus* | | | | R | R R | R R | R | | R R |
| | *decipiens* | | | R | C | | | | R R | |
| | *decipiens* fo. *singularis* | | | | | | | | | |
| | *Lorenzianus* | C C | C | R | C C | C C | R | R | R | |
| | *affinis* | + | | | + | + | | R R | + | |
| | *laciniosus* | | | R R | | | | R R | | |
| | *distans* | | | | | | | | | |
| | *Compressus* | R | R R | + | | | | | | |
| | *Van Heurckii* | | | | | | | | | |
| | *pelagicus* | | | | | | | | | |
| | *brevis* | | | | | | | | | |
| | *subsecundus* | | | | | | | | | |
| | *deversus* | | | R R | | | | | | |
| | *Messanensis* | R R | | | C | + | R R | | + | R R |
| | *Pseudocurvisetes* | | | | | | | | | |
| | *didymus* | | | | R | | | | | |
| *Biddulphia* | *sinensis* | | | R | | R R | | | R R | R R |
| | *pulchlela* | R R | | | | | | | | |
| | *mobilensis* | | | | | | | | | |
| | *longicrusis* | | | | | | | | | |
| *Hemiaulus* | *sinensis* | | | | | R | | | R R | |
| | *Hauckii* | | | | | | | | | |
| | *membranacus* | | R R | R R | R R | R R | R R | | | |
| *Cerataulina* | *Bergonii* | | | R R | + | | | | R R | |
| *Ditylum* | *sol* | C | R R | R R | + | | R R | R R | R R | |
| *Eucampia* | *cornuta* | | | | | R | | R R | | |
| | *zoodiacus* | R R | | | | | | | | |
| *Climacodium* | *Frauenferdianum* | | + | C | | + | | R | | |
| | *biconcavum* | | R | | R R | + | | + | ++ | R R |
| *Streptotheca* | *india* | | R R | | | R R | | | | |
| *Asterionella* | *japonica* | | | | | | | | | |
| *Thalassionema* | *nitzschioides* | + | R R | R R | | | | | | |
| *Thalassiothrix* | *Frauenferdii* | C | C C | + | R R | + | R | R | R R | |
| | *longissima* | | + | R R | R R | | | R R | + | R |
| *Pseudoeunotia* | *doliolus* | | R R | | R R | | | | R R | |
| *Nitzschia* | *seriata* | + | | R R | R R | R R | | | R R | |
| *Hemidiscus* | *cuneiformis* | R R | R R | R R | R R | | R R | | | |
| *Triceratium* | *gibbosum* | R R | | | | | | | | |

| 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | R R | | | |
| | | | | | | R R | R R | | R | | R R | R R | R | | | | | |
| C | R R | C C | C C | C C | + | C C | C | C C | C C | C C | C C | C C | C C | C C | C | R | + | R R |
| | C C | | | | | | | R R | R R | | | | | | | | | |
| | | | | | | | | | | | | | | + | | | R R | |
| | | | | | | R | R | | | | | R R | | | | | | R R |
| R R | + | + | C | C | + | C C | + | R | C | + | + | R | C | R R | + | | R | R R |
| C | + | R R | | R | | R R | R R | | R R | R R | R R | R R | R R | R R | R R | R R | R R | |
| R R | | R R | R | | | | | | | | R R | R R | | + | | | | R |
| | | R | | | | | | | | | | | | | | R R | | |
| R | R | | R | R | + | + | R | R | R | R R | R R | R | + | C C | C C | C | C | R |
| R R | R | R R | | R R | R | | | + | | + | | R | + | + | | | R R | + |
| | | R R | | R | | | | R R | R R | | | R R | | R R | | R | | |
| | R R | | R R | R | | | | | | R R | | R R | | R R | | | | R |
| | | | | | R R | R R | | | | | | | R R | C | C | C C | C C | |
| | | | | | + | R R | | | | | | | | | | R | | |
| | | | | | + | R R | | | | | | R R | | R | + | C | + | |
| | | R R | | R | R R | | | R R | | | | | | R R | R R | | | |
| | | | | | R R | | | | | | R | | | | R R | + | R R | |
| | | | | | R R | R R | | | R R | | | R R | | | | | | R R |
| | R R | R R | | | | | | | | | | | | | R R | | | |
| | | | | | R R | R R | R R | | | | | | | R R | + | R | + | |
| | | | | | R R | R R | | R | R R | + | + | + | + | C | C | + | C | |
| R R | R R | | R R | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | + | + | R | |
| | | | | | | | | | | | | | | | | R R | R R | |
| R R | | | | | | R R | R R | | R R | R R | | | R R | + | R | R | R | |
| | | | | | | | | | | | | | | R | | | | |
| | | | | | R R | | | | | | | | | | | | | R R |
| | | | | | R R | R R | | | | | | | | | R R | + | | |
| | | | | | R R | R R | | | R R | | | | | + | C | + | + | + |
| | | | | | R R | | | | | | | | | | | R R | | |
| | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | R R | + | | | |
| | | | | | | | | | | | | | | R R | R R | | | |
| | | | | | R R | R R | | | | | | | | + | + | C | + | |
| | | | | R R | R | R R | R R | | | | R R | | | C | C | C C | C | R R |
| + | C | + | C | C | C | C | | | R R | R R | R R | | | R R | R R | | | R R |
| | | R R | R | R R | R | R | R R | R | | | | R R | R | R | R | + | R | R |
| | | | | | | | | | | | | R R | R | + | C | C | C | R |

Remarks: CC, very common C, common +, present R, rare RR, very rare

## Ⅲ　珪藻類の組成並びに分布

本調査によって27属91種の珪藻類を同定することができたが，その詳細は第2表に示した。ベンガル湾におけるプランクトン構成種の主要なものは *Chaetoceros* 属，*Rhizosolenia* 属及び *Planktoniella* 属でありこれ等が多量に出現した。湾全水域に亘って広く分布を示したものに *Chaetoceros coarctatus*, *Planktoniella sol*, *Rhizosolenia alata*, *Rhizo. styliformis* が挙げられ，次いで *Chaetoceros Lorenzianus*, *Thalassiothrix longissima*, *Rhizosolenia hebetata* fo. *semispina*, *Rhizo. calcar-avis* 等もかなり広い分布を示した。しかしこれら種類は地点によって出現頻度を異にしている。分布が局部的で或る限られた水域のみに出現した種類に *Nitzschia seriata*, *Hemidiscus cuneiformis*, *Chaetoceros compressus*, *Chaeto. didymus*, *Chaeto. pelagicus*, *Chaeto. deverusus*, *Biddulphia sinensis*, *Ditylum sol*, *Bacteriastrum varians*, *Thalassionema nitzschioides*, *Thalassiothrix Frauenfeldii* 等が挙げられる。

このように珪藻類の分布状況並びに組成から本調査水域を次の通り5海区に分けることができる（第1図）。

A海区（St. 2～6）。　ニコバル諸島西岸水域で *Chaetoceros Lorenzianus*, *Rhizosolenia alata* が優勢に出現し，*Thalassiothrix Frauenfledii*, *Chaetoceros coarctatus*, *Rhizosolenia styliformis* var. *latissima* 等もこれらに次いで多く出現した。従来 *Planktoniella sol* は遠洋性種（暖海）の代表的なものとされているが，本区ではその出現度は低く，これに反し沿岸性種とされた *Nitzschia seriata*, *Chaetoceros compressus*, *Rhizosolenia fragilissim*, *Hemidiscus cuneiformis* 等が僅少ではあるが出現した。本区は遠洋性種と沿岸性種が混合したところであるが組成的には沿岸性種がやや優勢である。

B海区（St. 7～15, St. 18～20）。　アンダマン諸島西方のベンガル湾中央部水域であるが，*Planktoniella sol*, *Chaetoceros coarctatus*, *Rhizosolenia styliformis*, *Chaetoceros peruvianus*, *Thalassiothrix longissima* 等の遠洋性種が多量出現した。A海区に比し沿岸性種は減少しあるいは消滅して，組成は単調となり出現した種類の数は全海区中最も少なかった。本区は外洋性種が圧倒的に優勢な水域である。

C海区（St. 21～24）。　湾の北西部に当る沿岸水域で，*Chaetoceros coarctatus*, *Planktoniella sol* が多量に次いで *Chaetoceros peruvianus*, *Climacodium biconcavum*, *Biddulphia sinensis*, *Rhizosolenia styliformis* が出現した。特に本区の東部では *Chaetoceros Lorenzianus*, *Rhizosolenia alata* 等沿岸性種の出現度に増加が認められた。本区は各点ともプランクトンの組成は沿岸，遠洋両性種の混合水域と認められる。

D海区（St. 25～29）。　ビルマ・マレー半島沿岸沿いの湾東部に当る水域で，*Chaetoceros Lorenzianus*, *Chaeto. compressus*, *Bacteriastrum varians*, *Thalassiothrix Frauenfeldii* が優勢に出現し，次いで *Thalassiothrix nitzschioides*, *Nitzschia seriata*, *Skeletonema costatum*, *Biddulphia sinensis*, *Ditylum sol*, *Chaetoceros pelagicus* 等も多く，B・C海区に優勢に出現した遠洋性種 *Planktoniella sol*, *Chaetoceros coarctatus* は極度に減少している。*Rhizosolenia* 属で多くの沿岸性種が出現したのも特徴の一つであった。本区は沿岸性種の圧倒的優勢な水域である。

E海区（St. 16～17）。　B海区に隣接する湾西部水域で *Planktoniella sol* が優勢に出現した。B海区との顕著な相異点は *Chaetoceros compressus*, *Chaeto. pelagicus*, *Bacteriastrum varians*, *Ditylum sol*, *Skeletonema costatum*, *Cerataulina Bergonii* 等の沿岸性種が出現したことであった。これはセイロン島東部沿岸水の影響によるものと考えられる。本区は外洋性種と沿岸性種の混合水域である。

## Ⅳ 考 察

従来植物性プランクトンの出現状況によって，水塊の系統・起源等を推察されていたが，この場合植物性プラクトン個々の種を単独に用いるより種群として組成を比較するのがより妥当であり，独特な植物性プランクトンの種群は時期を限定すれば充分水塊の系統や特性を示し得るとされた。本調査では *Chaetoceros compressus, Chaeto. Lorenzianus, Chaeto. Pelagicus, Biddulphia sinensis, Bacteriastrum varians, Thalassionema nitzschioides, Thalassiothrix Frauenfeldii, Nitzschia seriata* 等が主として沿岸部に *Planktoniella sol, Chaetoceros coarctatus, Chaeto. peruvianus, Thalassiothrix longissima* 等が湾中央部に優占し，それぞれの水を指標している。これらプランクトンの出現状況から A, C, E 海区はそれぞれ強弱の差こそあれ沿岸水と外洋水の混合水域と考えられ，B海区は外洋水，D海区は沿岸水の影響が極めて強い水域と見做される。

珪藻類の分布の濃密な地点は湾北部から東部にかけての沿岸部で殊にイラワジ河，ガンヂス河の河口に近い St. 25, 27, 28であった。これはベンガル湾冬季（12～2月）の海流は，湾南部を東西に流れる北赤道流の支派がセイロン島並びにインド半島東部沿岸を洗い北上し南下する時計廻りの流動を行っており[1]，これら地点に沿岸部の栄養塩を供給していることが想像されるが，イラワジ及びガンヂス河の大河による栄養分の流入の影響も多少関係すると思考される。しかし本調査では水質分析を行なっていないので詳細については不明である。表層の水温の水平分布は低緯度で高く（St. 2において 28.3°C），北上するに従い低下し，北部沿岸が最も低い。これらの温度差は約 3.3°C であった。水温分布と珪藻類の分布との間には顕著な関連性は認められなかった。

## Ⅴ 摘 要

1）ベンガル湾冬季の浮游性珪藻類の組成は，湾中央部と沿岸部でその性状を異にしている。即ち，中央部では *Plnktoniella, sol, Chaetoceros coarctatus, Chaeto. peravianus, Thalassiothrix longissima, Rhizosolenia styliformis* 等の遠洋性種が優勢に出現し，これは北赤道流の支派の影響によると思考され，沿岸部では *Chaetoceros compressus, Chaeto. Lorenzianus, Chaeto. pelagicus, Biddulphia sinensis, Bacteriastrum varians, Thalassionema nitzschioides, Thalassiothrix Frauenfeldii, Nitzschia seriata* 等の沿岸性種が多く出現し，ベンガル湾の沿岸水はこれらの種属によって指標される。

2）珪藻類の濃密なところは湾北部より東部に亘った沿岸部で，特にガンヂス，イラワジ両河の河口附近に多いことが認められた。

3）珪藻類の出現状況から調査水域を5海区に類別することができる。即ち A, C, E 海区は外洋・沿岸双方の混合水域，B海区は外洋水域，D海区は沿岸水の影響が強い水域と看做される。

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# ノリ糸状体の生長に関する研究※

尾　形　英　二

Studies on the Growth of *Conchocelis*

by

Eizi OGATA

(With 12 Plates and 39 Text-figures)

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# まえがき

アサクサノリ *Porphyra tenera* KJELLMAN を主とするアマノリ類は，わが国における浅海増殖事業の重要な対象であり，その産額は平年作でおよそ 30 数億枚，金額にして 200 億円をはるかにこえ，わが国水産物中で重要な位置をしめている[59]。しかも需要の増大とともに年々新漁場が開発されて，生産が増加している。このようにわが国の海産有用植物中もっとも重要とみられるアサクサノリの増殖事業は，一見よく安定した発展途上にある産業のようにみえるが，数年前まではその豊凶の大勢を決定するタネツケは，主として気象や海況などの自然環境に左右されていた。しかし 1949 年に報告された DREW の糸状体の研究を端緒にして，ほぼアマノリ類の生活環があきらかにされてから，わが国ではその成果にもとづいて糸状体からの人工タネツケが発達し，今ではそれの企業化がおこなわれているほどの現状である。藻類学上の一発見がこれほどひろく実用化され企業化されて発展した例は他にあまりみられない。このように糸状体からの人工タネツケの発達によって，ノリ増殖事業はもっぱら天然タネツケに依存していた昔とちがって相当安定した産業の形態をそなえてきた。しかし人工タネツケが普及したほどには糸状体の基礎研究が進んでおらず，企業化が先行して理論がそのあとを追っている現状であるために，糸状体に関する基礎知識の欠乏にともなう事業の不安定がまだ各地にみられ，ノリ増殖事業の近代産業化にはまだ道遠しの感がある。

したがって，ノリ増殖事業をさらに安定させ，その生産を増加し，生産コストを下げてわれわれの食生活を豊かにするためには，糸状体の培養および人工タネツケを確実なものにしなければならない。そのためには糸状体の培養に関する基礎知識が必要であるが，今までのところその形態学的，生態学的研究の進展にくらべて，生長の理論に関する研究が少ない。

著者は，糸状体の培養および人工タネツケの技術をさらに確実にするための基礎研究として，糸状体の生長に関するテーマをとりあげ多方面から追究して多くの新知見をえ，ほぼ体系だって発表しうる段階にいたったので，いままでにえられた成果をまとめてここに報告する次第である。

この研究を進めるにあたり，いろいろご指導いただき，また論文をみていただいた九州大学・故瀬川宗吉教授，校閲とともに有益なご助言を与えられた京都大学・木俣正夫教授，終始激励とご助言をくださった京都大学・米田勇一博士，北海道大学・山田幸男教授，大阪市立大学・三木茂教授，京都大学・松原喜代松教授の諸先生に謹んで感謝申しあげる。

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## 研 究 史

チシマクロノリ *Porphyra umbilicalis* (LINNÉ) KÜTZING の生活史においてみられる糸状体 *Conchocelis*-phase について DREW (1949) が発表して以来，*Porphyra* および *Bangia* の生活史に関する研究が急にさかんになってきた。すなわち DREW (1952, '54, '56, '58) は，ひきつづきチシマクロノリの1変種やウシケノリ *Bangia fusco-purpurea* (DILLWYN) LYNGBYE の生活史および生殖に関する研究を発表し，また GRAVES (1955) は *Porphyra capensis* KÜTZING の生活史について報告をしている。

わが国においては，黒木 (1953a, 1956) の研究にはじまって，アサクサノリ糸状体に関する多くの報告がみられるようになった。そのうち，中村 (1953)，須藤 (1953)，新崎 (1954)，殖田 (1958)，吉田 (1956) などは主として啓蒙的立場から糸状体について言及している。

中国においても TSENG and CHANG (1955a, b) がアサクサノリの生活史およびその有性生殖について発表している。

一方ノリ増殖上における人工採苗の問題に関してわが国の多くの研究者が生態学的研究に従事し，とくに糸状体からの胞子放出に関する報告が多く出されている。黒木 (1953b)，須藤 (1954)，須藤他 (1954)，竹内他 (1954)，黒木・平野 (1955a, 1956a, b)，斉藤 (1955, 1956a)，曽・張 (1956)，山崎 (1954b) などの報告がそのおもなものである。また太田 (1954) は人工採種試験に関する報告を発表して人工タネツケの企業化への端緒を開いている。

また，貝殻以外の基物に対する穿孔生長について OGATA (1955)，右田・太田 (1957) が，糸状体の貝殻中における垂直的生長について OGATA (1959) がそれぞれ研究の端緒を開いている。その他糸状体の病害に関するものとしては太田 (1958)，野沢他 (1959) の報告がみられる。

以上は，糸状体の形態学的，生態学的研究のあらましであるが，直接この研究に関係のある報告は比較的最近のものが多いため，本文中の関係各項でふれることにした。

# 第1章　ノリ糸状体の生長に関する形態学的研究

DREW (1949) に端を発した糸状体に関する研究が，その後急速に発展したために，アサクサノリをはじめとするアマノリ類の生活環がほぼあきらかになったことは，まえがきにのべたとおりである。そして糸状体が，アマノリ類の生活環中における一時期であるということが，ほぼたしかめられるにいたり，このようなことは今日ではすでにノリ業者などの常識的知識にさえなっている。

このように，ある種の藻類が互に形態のことなる時期を経過して，その生活環を完了するという例は少なくないが，アマノリ類のばあいではその糸状体がふつうにみられる葉体 (thallus) と全く形態をことにするばかりでなく，貝殻に穿孔して生長するという点において，大いに興味がもたれてきた。

そして，歴史的にみるとまず貝殻中における糸状体の穿孔，およびその後の生長の形態学的追究がさかんにおこなわれ，わが国では黒木 (1953a) などの研究によってほぼそのあらましがあきらかにされた。その結果によれば“アサクサノリをはじめとする数種類のアマノリ類の果胞子は，その培養によって発芽管を出して発芽し，糸状体となる。それらが貝殻上で発芽したときは，発芽と同時にまた少しは匍匐してから貝殻の内層に侵入し，侵入した発芽管は，先端生長をおこなって生長し複羽状に多数分枝した放射状の糸状体となる。この糸状体は穿孔藻の一種 *Conchocelis* と形態において一致する。アマノリ類の糸状体の間においては，その種類による形態学的差異はいくらかの点で多少みとめられるが識別はきわめて困難である”。

糸状体の基物となる貝殻には，初期の研究では，マガキ，ナミマガシワ，マテなどがもちいられたが，人工採苗法の発達以来，事業的には大きくて入手しやすいスミノエガキやイタボガキなどのカキ殻が好んで用いられるのでその後の研究ではこのようなカキ殻が主としてもちいられる傾向がある。

上述のように，糸状体の生長に関しては，あるていど形態学的研究の成果があげられているが，まだ未解決の点も少なくない。本章ではこれらのうち，とくに貝殻中における垂直的生長および，カキ殻以外の諸種基物中における生長の問題をとりあげ，その形態学的研究をおこなった結果についてのべる。

## 第1節　糸状体の垂直的生長

糸状体に関するいままでの研究では，その形態の観察をはじめとするすべての実験において，糸状体は貝殻などの基物の表面からのみ観察されている。したがって，貝殻などの基物の深層においては，どのような生長状態をしめすものか，ほとんど知られていない。

ただ DREW (1958) はウシケノリの研究において，貝殻の一方の面から穿孔して生長した糸状体が，それを貫通して他の面まで達し，そこでふたたび繁茂することをみているが，貝殻深層中の状態についてはくわしい観察がない。また TSENG and CHANG (1955a) は貝殻を脱灰した材料について，貝殻深層部のアサクサノリ糸状体を観察しているが，脱灰という手段によってその状態はいちじるしく変形し真の状態を観察したものとはいえない。したがって，貝殻深層部における糸状体の生長状態が観察できれば，いままでの平面的観察にとどまっていた糸状体の生長の全貌が，あきらかになるものと考えられる。筆者はいろいろ工夫した結果，貝殻を切断して断面をつくり，これを薄片として貝殻深層中における糸状体の状態を観察する方法を考案し，ほぼ目的を達することができた。

糸状体を培養するばあい，ふつう果胞子は貝殻の内面に播種されるから，この面が上面になり，殻皮の側，すなわち外面は下面になる。つまり貝殻をほぼ平板とみると貝殻面は水平方向であり，その断面は垂直方向となる。したがって，便宜上表面観察による糸状体の生長を水平的生長，断面観察によるものを垂直的生長とよぶことにする。

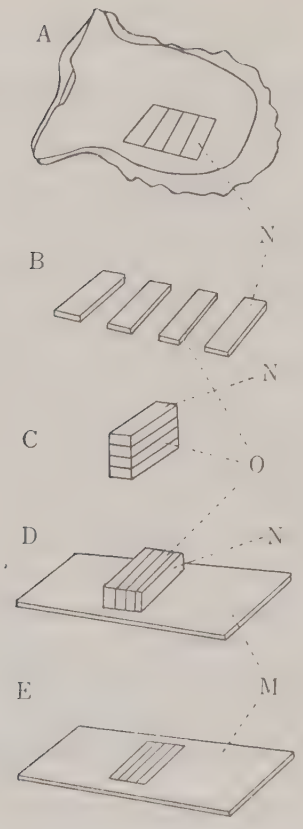


Fig. 1. Procedure used in preparation for observation of the vertical growth in *Conchocelis*.
A : *Conchocleis*-inhabited shell.
B : Rectangular shell pieces are cut out of the shell.
C : Shell pieces are piled and cemented together into a block.
D : The block is made to adhere to a microscopic slide.
E : Upper surface of the block sticked on a microscopic slide is ground and thinned to facilitate the microscopic observation.
N : Inner surface of shell. M : Microscopic slide. O : Surface of section.

## 材料および方法

糸状体の母藻は，下関市吉見地先で増殖されていたアサクサノリである。供試貝殻には，カキ殻よりも透明で細胞の小さいアコヤ貝の殻をもちいた。なお殻の外側に存在する殻皮と角質層を除いたものも実験に供し，比較した。

播種は1958年12月６日と12月18日にそれぞれおこなって２系列の培養をし，この両者から適宜一定期間ごとにサンプリングをおこなった。ふつうにおこなわれている播種と同様の方法で，アサクサノリのいわゆる果胞子を貝殻の内面を上にして全面にまき，自浄海水をもちいて直射日光のあたらない室内（500～2,000 lux，室温）で培養した。このようにして培養された糸状体の垂直的生長を，つぎのような著者の考案した

方法で観察した（第1図A～E）。まず，10％ホルマリン海水で固定した貝殻（第1図A）の任意の部分を切断して，短冊型の小片を数個切りとる（第1図B）。それらを重ねあわせて，たがいにレークサイドセメントで接着して貝殻小片のブロックをつくる（第1図C）。このブロックの面のうち，貝殻小片の断面ばかりをそろえた面のどちらかを，よく砥石ですってなめらかにし，この面とスライドグラスとをレークサイドセメントで接着する（第1図D）。つぎにスライドグラス上に接着されない面を，きわめてうすく（100～200μ）なるまで荒砥ですりへらしたのち（第1図E），目の細かい砥石で断面をなめらかにし仕上げとする。このようにして貝殻の断面のプレパラートをつくり，さらに流動パラフインを被覆すれば透明になって糸状体が穿孔している断面の様子が検鏡しやすくなる。

## 結果Ⅰおよび考察

播種5日後の貝殻断面をみると，すでに糸状体は下方にむかい穿孔生長して20～30μに達している（図版ⅠA）。これらははじめ1本であって，垂直に，あるいは斜に下方にむかう。10日間の培養では80μ前後の深さに達する（図版ⅠB）。培養が20日におよぶと垂下した糸状体の基部，すなわち貝殻の表面下5～20μのところから枝がでて，あるものは水平方向にはしり，あるものは垂下して垂直の枝がふえるようになる（図版ⅠC；図版ⅡA・B）。そして垂下した枝は200μ前後に達し，水平の枝も表面下30μ以内の層で密になり，分岐が多くなる。そして表面直下の層を侵蝕して，ところどころ表面に達している。

培養がすすむにしたがって垂下する枝はますます伸長するが，同時に水平の枝の発達もいちじるしく，表面からみると，これまで多くの人々によって観察された糸状体の形状と同じような放射状生長をしめす（図版ⅠⅠ～M）。

30日のものでは垂下する枝は300μ前後に達して，その中央部に近い部分からも枝がわかれるが，それは彎曲しながら斜上して表面に達する傾向をしめす（図版ⅠD）。このころには水平方向の繁茂のために，表層の糸状体の形状は複雑をきわめて観察が困難になる。

60日目になると，垂直の主枝は750～800μに達し，肉のうすいアコヤ貝殻では，多くが下面（殻の外面）の稜柱層に達する。そして培養のはじめに外面（下面）の殻皮および稜柱層をのぞいてあった部分では，垂直の枝が真珠層を貫通して下面にとどく（図版ⅠE）。また下面に達した垂直の枝のはしに近い部分からでた枝は，上面に近い枝分れのばあいと逆に下面にむかって伸長する。この枝は100日目（図版ⅠF），130日目（図版ⅠG）と日がすすむにつれ増加する。100日目のものではほとんどの垂直の枝が稜柱層に達している（図版ⅠF）。130日目の殻皮および稜柱層をのぞいてあった部分の断面においては，はじめに播種した側がどちらであったか判別にこまるほど，両面に近いところで糸状体が繁茂する（図版ⅠG）。そして垂直の枝は貝殻の厚さが1,000μにおよぶものも，これを貫通して内外面に達する。

上述の観察から，糸状体の枝には基物の面に沿ってその直下を水平にむかう傾向をしめすものと，面から遠ざかって垂直に内層にむかう傾向をしめすものがあり，後者の途中から生ずる枝分れは，ほぼ中央部から上にできたものは上方に，下の部分にできたものは逆に下方にむかう性質をもっているものと思われる。稜柱層の中でも糸状体は発達するが，真珠層中ほどの繁茂はみられないようである（図版ⅠF）。

上述したような糸状体の生長は，カキ殻中においても同様にみられる。1958年1月23日に播種して約1年培養したカキ殻中の糸状体の断面を，アコヤ貝殻のばあいと同様にして観察したところ，不透明で観察しにくいが，やはり内外面に貫通する垂直な糸状体の密な存在がみられた（図版ⅠH）。したがって糸状体の生長様式はカキ殻でもアコヤ貝殻でも本質的に差がないとみとめられる。カキ殻の稜柱層中では，糸状体の生長は非常に少ない。

アコヤ貝殻を基物として播種したばあい，めだつことは閉殻筋痕（impression of adductor）の部分には糸状体がよく繁茂することである。閉殻筋痕は貝殻の内面に透明層あるいは光輝層（hypostracum）といわれる部分が露出しているところ[25]であるが，糸状体が真珠層の部分よりここで繁茂する理由としてはつぎ

のようなことが考えられる。すなわち横断面でみると，光輝層には高さ 30～50μ 前後の垂直な小さな結晶がならび，他の真珠層の部分より透明であるから，真珠層より光がとどきやすい。したがって透明層中においては真珠層中より糸状体が繁茂しやすいのであろう。

## 結果Ⅱおよび考察

つぎに，表面のごく近くでの穿孔状態をくわしくみるために，はじめから貝殻の断面に播種して，その生長を観察した結果についてのべる。

方法としては，未播種のアコヤ貝殻をもちい，まえと同様（第1図A・B）にして貝殻小片のブロック（第1図C）をまえもってつくり，そのあたらしくできた断面（第1図C～O）をよくなめらかにして，その面に播種をおこない（1959年2月22日）そのまま培養をつづけた。プレパラートは，培養中のブロックのはしから1片ずつはぎとり，もとの自然面（第1図C～N）を砥石ですってうすくし，そのままスライドグラスにはりつければ，断面にまいたばあいの表面直下の穿孔状態がみられる。

20日目（図版ⅡA・B），30日目（図版ⅡC），50日目（図版ⅡD），70日目（図版ⅡE）と生長していくが，倍率を高めて観察すると（図版ⅡD），枝わかれの様子や，それが表面に達する様子がよくうかがわれる。

これからみると，生長の初期には，平面的にはもちろん立体的にも放射状であることがわかる。しかしこの培養における水平的生長，すなわち断面に播種したものの生長をその面（第1図C～O）で観察すると，貝殻の自然面（第1図A～N）に播種したばあいにみられるふつうの羽状生長とは，かなりことなった様子をしめす。すなわち，図版ⅠのⅠ～Mにみられるような形態でなく，図版ⅢA・Bにみられるように糸状体の枝が貝殻のもとの自然表面（第1図C～N）の方にむかって生長し，そこに達する傾向がみられる。これは糸状体が穿孔生長中に分枝するばあい，その枝は比較的近い方の表面にむかって伸長する傾向があることをしめす。

## 要　　結

1. アコヤ貝殻を基物として，アサクサノリ糸状体の垂直方向の生長を観察した。
2. はじめ母胞子から垂直方向に1本の糸状体が穿孔して垂下するが，表面直下の基質では水平方向にも枝かでる。
3. 表面近くの枝は，さらに枝わかれして陸上植物の匍匐枝のようにのびて，ところどころで表面に達する。
4. 生長がすすむと，このような枝は表面下 20～30μ までの層で非常に稠密となる。
5. 直根状に垂下する枝は，100日も培養すると貝殻の下面に達する。
6. 貝殻内層のほぼ中央部から上方で発出する枝は上にむかい，下部で発出する枝は下にむかい，それぞれ両面に達する傾向がある。
7. 閉殻筋痕の部分には糸状体がよく繁茂する。
8. カキ殻中と，アコヤ貝殻中とでは，糸状体の生長に根本的な差はみとめられない。

## 第2節　糸状体の生長の方向性について

糸状体が貝殻内層中で垂直方向に穿孔生長して，ついには下面に達することは第1節にのべたとおりであるが，このような直根状の生長が重力に関係があるものかどうか面白い問題と思われる。ふつうにおこなう糸状体の培養では，貝殻の内側を上にして水平におき，その上に播種するから，直根状の枝は貝殻面（播種面）に直角に，すなわち重力の方向に内層にむかって生長するわけである。もちろん，このような垂直に生長する枝（以下内向枝とよぶ）の他に，貝殻面直下の表層中で生長する枝（以下表層枝とよぶ）も存在す

る。これは主として表面に平行に走るわけで，したがって重力とほぼ直角の方向性があることになる。このような生長の方向性が貝殻面の角度を変えた培養によって変化をしめすかどうか，二，三の実験をおこなって観察した。

## 材料および方法

最初にアコヤ貝殻から短冊型（約1 cm × 3 cm）に切りとった小片を数個用意し，それらの内面（真珠層側）を上にして下関市吉見地先産アサクサノリの果胞子を播種（1959年1月14日）した。果胞子がよく附着するのをまつために1～2日静置してから，これら貝殻小片の一端に穴をあけて，海水容器中につるし，その状態で培養した。すなわち貝殻の面はたてになっている。

この中から順次貝殻小片をとりはずしてサンプリングをおこない，その断面を作って観察した。断面を作る方法は第1節にのべたとおりであるが，この実験では，つるしていた小片の上下をマークして断面を作らなければならない。すなわち，小片を上下の方向に切断して，さらに小さな短冊形の小片にし，その上下端をマークしたのち，レークサイドセメントで接着してブロックにする。その後はまったく同様にしてプレパラートに作りあげるが，プレパラート上でもとの小片の上下方向が認識できるようにしておくわけである。つぎに，貝殻面を逆にしたばあいの影響をみるために，播種した面が下側になるように貝殻を伏せて培養をおこなった。播種（1959年2月1日）ののち胞子をよく附着させるために1～2日そのまま静置してから，培養にうつした。貝殻を伏せたばあい，上側になる面には稜柱層および殻皮がおおっているが，これらをとり除いたものと，除かないものと両方について実験をおこなった。なおふつうに播種面を上にしたものを対照とした。

## 結　果　Ⅰ

貝殻をたてにつるして培養したものの15日目の断面をみると，内向枝は貝殻の内層にむかって生長し，長さ約150 μに達している。この様子はふつうに水平に培養したばあいとかわらない（図版Ⅳ A）。

30日目のプレパラートでは内層350 μに達する枝がみられる（図版Ⅳ B）。このころには，いわゆる表層枝の発達もいちじるしく，匍匐枝のように表面直下の層で密になる。培養40日目におよぶと，いわゆる内向枝は長さ500 μに達している（図版Ⅳ C）。そして貝殻面から遠ざかって内層にむかっている。すなわち，貝殻面がたて（重力方向）であるから，いわゆる内向枝は，重力方向に直角に生長したことになる。

110日目になると，いわゆる内向枝は，真珠層を貫通して殻皮側に達するようになる。そして稜柱層の中でも分岐して生長している。このような貝殻面をたてにして培養した糸状体の生長経過をみると，いわゆる内向枝はやはり貝殻面から遠ざかって内層に，表層枝はやはり表面に平行に生長している。いいかえると，貝殻面がたてであっても水平であっても，糸状体の生長方向は，貝殻面に対してつねに同じ関係をたもつといえよう。これは貝殻面に対する関係だけからみると，まったくふつうに水平に培養したばあいとかわらない。すなわち，糸状体の生長には重力は関係がないらしくみえる。

貝殻小片の面を，それぞれ別な方向にむくようにつるして，室内散光のもとで培養したから，光の影響はないものと考えてよい。このたて培養の40日目のものの表面観察は，水平培養のときと大差がみとめられない（図版Ⅳ D）。しかし，110日のものをみると多少一方にしだれているような生長傾向がみられるところもある（図版Ⅳ E）。

培養15日目のもののなかに，下端が鋸歯状の面をしたものがあったが，偶然にその各面に同時に穿孔した糸状体がみられた（図版Ⅳ K）。これをみると，内向枝は果胞子の附着した面にそれぞれ直角で，重力の方向と無関係なことがよく観察される。

## 結　果　Ⅱ

播種面を下にして伏せて培養した結果はつぎのようである。

培養30日目のものでは，断面をみると，やはり糸状体は貝殻の内層にむかって300μの長さに達している。播種した面が下面になっているから，これは重力にさからって上方にむかったことになる（図版Ⅳ F）。これは，上面になった稜柱層や殻皮をはじめから除いて，真珠層のみにしていたばあいである。それらを除いてなかったとき（図版Ⅳ G）は，これより生長がよくない。やはり殻皮などが存在すると光の量が不足するためと考えられ約200μぐらいしか生長していない。

播種面を上にしてふつうに培養したもの（対照）と，上面の殻皮などを除いて伏せて培養したものとをくらべると，やや対照の方が生長がよい傾向はあるが，一般に大差がみとめられない。

培養が95日におよぶと，真珠層のみの厚さ約750μのものでは，糸状体が下面（播種面）から上面（殻皮側）に達して，ふたたび上面の直下で密に繁茂するようになる（図版Ⅳ H・I）。

殻皮をつけたまま，その方を上にして培養したものでも，糸状体は下から稜柱層まで達しているが，全体に繁茂のていどがよくない（図版Ⅳ J）。

すなわち，いわゆる内向枝は，重力に抗して上方に生長している。しかし，播種面に対してはやはり直角に近い角度で，表面から遠ざかる傾向にある。このことは，たての培養，水平の培養，うつぶせの培養，いずれのばあいにもかわりがない。

## 考　　察

上述の観察からあきらかなように，貝殻の面（播種面）と，糸状体の生長方向とは，つねに一定の関係があることがわかる。すなわち，貝殻面が上むきであろうと，たてであろうと，下むきであろうと，糸状体の内向枝はつねに貝殻面から遠ざかって，内側にむかう傾向がみられる。また表層枝はつねに貝殻面に平行な層で生長する。いいかえれば，糸状体の貝殻中における生長に対して，重力の影響はみられないといえる。

光の条件は室内散光であるが，いずれのときも，光によってとくに生長方向が変化したようすはみられない。ただ，伏せたばあいには，上側に殻皮があるかないかで，生長のていどに差がみられたが，これは光の量の問題と思われる。したがって垂直方向の生長に対する光の影響は少ないとみられるが，水平方向の生長のごく初期には，枝が一方むきにそろっているときがみられる。これは光の影響かもしれない。この点に関してはまだ検討を要する。

たてに培養したばあいに内向枝が多少斜め下にむかう傾向があることもあるが，対照にもところによっては一方向に傾くことがあるから，かならずしも重力の影響とはいえない。これまでの考察から，糸状体の生長方向を規制するものは重力以外のものと考えられる。すなわち糸状体の生長には，tropism があるが，その刺激となるものは，重力以外のものと思われる。

## 要　　結

1．糸状体の生育する貝殻を海水中で，たてに，あるいは伏せて培養し，その生長方向を観察した。
2．その結果，貝殻面（播種面）が，上，下，横，いずれをむいていても，糸状体の生長状態には変化がみられない。
3．すなわち，糸状体は貝殻の面に対して，常に一定の方向に生長し，重力には関係がない。

## 第3節　各種貝殻中における糸状体の生長

糸状体を培養するばあい，卵殻などを基物にしたこともあったが，多くは貝殻がもちいられてきた。すなわち，なかば習慣的にカキ，ナミマガシワ，マテなどの殻がもちいられていた。しかし，この基物となる貝殻の種類がことなると，その中に穿孔する糸状体の形態に差があらわれるものかどうか，とくにその点を比較した研究はみあたらない。それでこの点をしらべるために，分類学上の科のことなる数種類の貝殻に糸状体を培養したばあいの，生長状態や形態を，貝殻の表面と断面から観察をおこなって比較した。

## 材料および方法

供試貝殻は

スミノエガキ *Crassostrea rivularis* (GOULD)
アコヤガイ *Pinctada martensii* (DUNKER)
ハマグリ *Meretrix lusoria* (RÖDING)
オオノガイ *Mya japonica* JAY
ブタノツメ *Quadrula metanerua* RAFINESQUE
マダカアワビ *Haliotis gigantea* GMELIN
タイラギ *Atrina pectinata japonica* (REEVE)

の7種である。前実験と同様下関市吉見地先で増殖されたアサクサノリの果胞子を，これらの貝殻の内面を上にして播種し，室内の約 500 lux の螢光燈のもとで培養した。培養は，1959年12月12日に開始し，1960年1月11日までの生長を前記と同様の方法で観察した。タイラギについては，1959年12月20日から1960年1月11日までのものである。

## 結　　果

**ハマグリ**：ハマグリ殻を基物にしたばあい，その水平方向の生長（図版ⅤA）はカキ殻やアコヤ貝殻のばあいと少しことなった形状をしめすようである。すなわち，糸状体の枝が直線的に長くのびる傾向をしめす。ハマグリ殻を基物にした研究は TSENG and CHANG (1955a) がおこなっているが，このような点についてはのべていない。

つぎにハマグリ殻の断面をつくってみると，アコヤ貝殻のばあいとことなってかなり不透明な真珠層をもっているが，その内層にむかう垂直的生長がみられることはアコヤ貝殻のばあいとかわりがない(図版ⅤB)。

**オオノガイ**：オオノガイ殻の中に穿孔した糸状体は，表面からみるとハマグリ殻を基物としたばあいによく似た生長をしめすようである（図版ⅤC)。すなわち表面近くの層を水平にながく直線的に枝をのばして生長する傾向がみられる。オオノガイ殻には真珠層に表面に平行した成層が多いために，内層にむかう垂直生長が比較的さまたげられているような傾向がみられる（図版ⅤD)。そのためか表面直下の層で繁茂することが多い。このことが表面からみたときの形に関係があるかどうかはあきらかでない。

**ブタノツメ**：厚くて比較的透明な真珠層をもっている俗称ブタノツメを基物にしたばあい，糸状体の生長は水平方向の生長（図版ⅤE）も垂直方向の生長（図版ⅤF）も，とくにアコヤ貝殻中の生長とことなる点はみられない。

**アワビ**：貝殻の内面がアコヤ貝殻と同じような真珠様光沢をしめし，その真珠層もかなり透明なアワビは，基物として表面が凹凸に富んでいる以外，ほとんどアコヤ貝殻とかわらないようである。アワビ殻の中における糸状体の水平方向の生長（図版ⅤG）も垂直方向の生長（図版ⅤH）もアコヤ貝殻中の生長とほとんど区別がつかない。この点はブタノツメのばあいよりさらによく似ている。このことは貝殻の成分や組成が外観とともによく似ていることをしめすようにおもわれる。

自然海中のアワビ殻中にみられた糸状体については，福原（1957）の観察があるがあまりくわしい記述がないので比較ができない。

**タイラギ**：タイラギの貝殻は以上の4種類の貝殻にくらべて，かなりことなった性質をもっているようである。すなわち，全体にやわらかくてセルロイド状の感触をしめしているが，これはタイラギの貝殻に水分*

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* 真珠の化学的組成[25]（%）

| | $CaCO_3$ | 水 | 有機物 | その他 |
|---|---|---|---|---|
| 黒蝶貝 | 91.72 | 2.23 | 5.94 | 0.11 |
| タイラギ | 72.72 | 23.06 | 4.21 | 0.01 |

真珠とその母貝の貝殻の化学的組成は同一であるといわれている。

が多いためと思われる。その真珠層は紫褐色でやや不透明であり稜柱層は表面からみると蜂巣状の構造をもっている。貝殻内面の大部分は真珠層でうらうちされているが，縁辺部は稜柱層のみ露出している。

このようなタイラギの殻について，真珠層と稜柱層に同時に播種した。真珠層に穿孔した糸状体は，表面からみるとアコヤ貝殻の真珠層で生長した糸状体と大差のない形態をしめしている（図版ＶＩ）。また垂直的生長の状態（図版ＶＪ）もまったくアコヤ貝殻のばあいとかわりがない。しかし，稜柱層の上に直接播種されて穿孔生長した糸状体は，かなりことなる様子をしめす。すなわち図版ＶＫにみられるように，蜂巣状の区画中に穿孔した糸状体は，おもにそのなかでのみ生長して，あまりしきりの外に出る様子がない。なかには先端がとなりの区画にはいりこんでいるものも少数みられるが大部分は一つのコンパートメントの中でのみ生長している。この状態を断面でみると図版ＶＬのようである。たてのしきりに沿って垂直に生長して，側枝があまり発達していない。このような稜柱層のたてのしきりに，糸状体の生長が規制される状態は，アコヤ貝殻の稜柱層中でもみられる現象である。このことは稜柱層の蜂巣状構造のしきりが，なにか酸にとけにくい有機物を含んでいることを予想させる。事実アコヤ貝殻の稜柱層では，このしきりの壁はコンキオリンであると報告[25]されているから，タイラギ殻のばあいもやはりコンキオリンの壁であろう。

培養の初期における稜柱層中の生長はこのようにかわったものであるが，これがさらに培養をつづけたばあいどのように変化するか，なお実験をつづけている。

**カキ，マテガイ，イタヤガイ等**：カキ殻中に穿孔したばあいについては，すでにのべたように，その真珠層の断面が不透明で観察しにくいが，貝殻内層にむかう垂直的生長がみられる。このことはマテガイ *Solen gouldi* CONRAD，イタヤガイ *Pecten albicans* (SCHRÖTER) などの貝殻についてもまったく同様である。これらの真珠層がかなり不透明な貝殻は，また質がもろく断面のプレパラートを作る作業がむずかしくうすくなりにくい。したがって，断面観察は困難であって垂直的生長がみられるという以外にくわしいことは観察できなかった。

## 考　　察

以上の観察から考えられることは，同じ種類の糸状体でも貝殻がことなれば，その中で生長したときの形態が多少はことなることがあるということである。すなわち，ハマグリやオオノガイのようにもろい陶質で成層のめだつ貝殻中では，糸状体は直線的に長く水平方向の枝を出す傾向がみられ，アコヤ貝に似た真珠層をもつブタノツメ，アワビなどの貝殻では，やはりアコヤ貝殻中の生長とかわらない水平および垂直的生長をしめすようである。

これらの貝殻による差は，貝殻の種類による組成と関係があるものかどうかはあきらかでないが，全く関係がないともいえないと思われる。

タイラギの稜柱層中で糸状体が独得な生長をしめすことは，糸状体の生長が基物の構造に影響される結果であって，次章の方解石やセメント中の生長のばあいと比較して興味がふかい。

## 要　　結

1. アサクサノリ糸状体はハマグリ，オオノガイの貝殻中では水平方向に直線的に枝をのばす傾向がみられる。
2. ブタノツメ，アワビ，タイラギなどの貝殻の真珠層中ではアコヤ貝殻中の生長とかわらない様子をしめす。
3. タイラギの貝殻の稜柱層中では，その蜂巣状の区画の中でのみ生長して，区画外に枝をのばすことが少ない傾向がみられる。

## 第4節　貝殻以外の石灰質中における生長

糸状体に関するいままでの研究では，その穿孔基物としておもに貝殻がもちいられ，ときに卵殻などが基物にされたこともある。これら以外のものではカメノテの一種 *Pollicipes cornucopia* の柄鱗（peduncular scale）中に穿孔していた糸状体の例が DREW *et al.*（1953）によって報告されている。また右田（1957）は石灰藻の石灰質部に糸状体を穿孔させて，その生長を観察している。

以上の基物はすべて生物起原の炭酸カルシウム性物質であって，それ以外の基物，とくに無機質に対する穿孔性についての研究はあまりみられずわずかに雲母，木，竹，石灰石等を基物にした例があり，結論として貝殻，卵殻などの生物起原のもの以外には穿孔しないといわれている。[4] しかし，貝殻と同じく主成分は炭酸カルシウムであるのに，石灰石などの鉱物性基物には穿孔しないという結果に疑問がもたれたので，方解石や石灰石などの鉱物性石灰質を基物として，糸状体の培養実験をおこなった。その結果，鉱物性石灰質中でも，貝殻中のばあいと全体としてはとんどかわりのない糸状体の生長がみられることがわかったので，それを形態的にくわしく観察した。ただこのばあい基物としてもちいた材料の関係から，第1～3節にみられるような断面をつくって垂直的生長を観察する方法が困難であったので，すべて表面観察による水平方向の生長のみしらべた。ここではその結果についてのべる。実験観察の期間が1955年2～12月のばあいは，用いた母藻は大阪湾で，1958年以降のばあいは下関市吉見地先でそれぞれえられたものである。

### A. 方解石中の生長

純粋に鉱物性起原である石灰質として，方解石を穿孔基物として実験をおこなった。方解石は六方晶系に属する炭酸カルシウムの結晶であって calcite とよばれる。用いた方解石は，ほぼ 1 cm × 1.5 cm × 0.5 cm 前後の透明な平行四辺体のものである。

#### 結果および考察

**アサクサノリ**：1955年2月28日に方解石上で発芽した糸状体は3月27日には第2図にみられるような穿孔

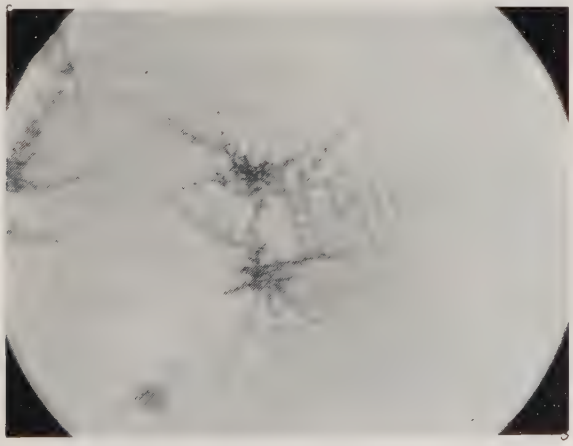

Fig. 2. *Conchocelis*-phase of *Porphyra tenera* KJELLMAN growing in calcite. ×60. Photographed on March 27, 1955 after 27 days cultivation.

生長をしめした。これでみるとカキ殻に穿孔したばあいと同じように，母胞子を中心として主枝が発出した複羽状の形態をしめすことが多い。また4月5日に方解石を基物として発芽したものは，10日後の観察では

第3図にみられるようにいろいろな形状をしめして穿孔していた。しかし，なかにはガラス上の発芽のよう

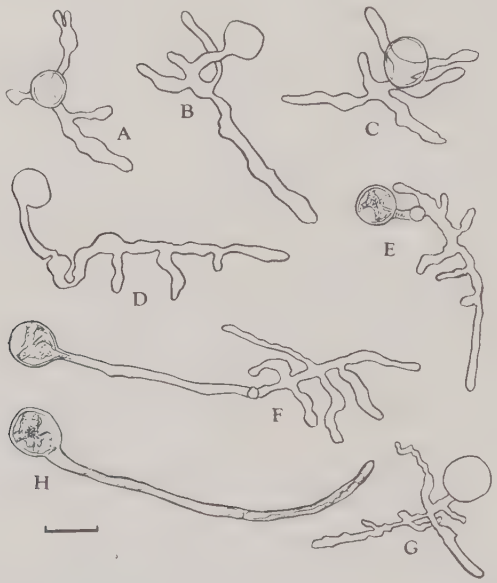


Fig. 3. *Conchocelis*-phase of *Porphyra tenera* KJELLMAN growing in calcite, cultured for 10 days. A～D : Immediately penetrating ones, E・F : Boring begins far apart from mother spores. G : Right-angled branching. H : Germling creeping on the surface of calcite without penetrating growth. Scale 15 $\mu$.

に，穿孔せずに基物面上をはっているものもかなりみられた（第3図H）。原胞子からの発芽管がただちに穿孔しないで，あるていど面上で生長したのち穿孔にうつったものもみられた（第3図E・F）。原胞子が空虚になっているものも内容がまだ存在しているものもともにみられた。このような方解石中における初期の生長の形態は，貝殻中のばあいに報告されたものとほとんどかわることがないようである。しかし方解石中の生長においてめだつことは，糸状体の細胞が貝殻中のばあいとことなって，なめらかな縁辺をしめさない部分があることである。すなわち第3図Gのような角のめだつ枝をもつものがかなりみられた。方解石中の糸状体に全部このような主角のある枝がみられるわけではないが，貝殻中ではこのような傾向がみられることはない。したがって，このような傾向は基物である方解石と関係があるものと思われる。すなわち，細胞の面が方解石の劈開の方向に沿う傾向があるために，このような形態をしめすことがあるものと考えられる。

一般に，生長の初期においては，方解石中の方が貝殻中より糸状体の幅がひろく，枝が鈍端になる傾向がみられる。方解石中で生育した糸状体は，その年の夏には高温のために枯死したものが貝殻中のものにくらべて多かった。

1960年2月22日にあたらしくもとめた方解石をもちいて，同様な実験をふたたびおこなってその経過を観察したところ，1955年のばあいにくらべて一般に発芽から穿孔までの期間がながく，方解石の面上を約1月前後も匍匐する傾向がみられた。

このように匍匐している期間のながい糸状体を，方解石の面上からぬぐいさって観察すると，穿孔するまでに面上をはっていた糸状体の細い条痕がはっきりとみとめられた。

またこの実験では，まえのばあいにくらべて，穿孔した糸状体が主角のある形態をしめすばあいがはるか

に多かった。

このように，基物が同じ方解石といっても，おそらく産地のことなるとおもわれる別個の方解石をもちいると，糸状体の匍匐期間や穿孔したばあいの形態にあるていどの差がみられることがあるが，このような現象は，方解石の性質の差ばかりでなく，その時の胞子の状態にも関係があるとも考えられる。

**ウシケノリ**：ウシケノリを母藻にして1955年２月28日に方解石上に播種した。このばあい穿孔しないで直立葉体になったものが多くあらわれたが，なかには穿孔して糸状体になったものもみられた。第４図は３月27日に観察したものである。果胞子嚢の多くできていた母藻を材料にしても，このようにウシケノリのばあいには，直立葉体があらわれることがしばしばあったが，発芽して穿孔したものの原胞子が果胞子であり，

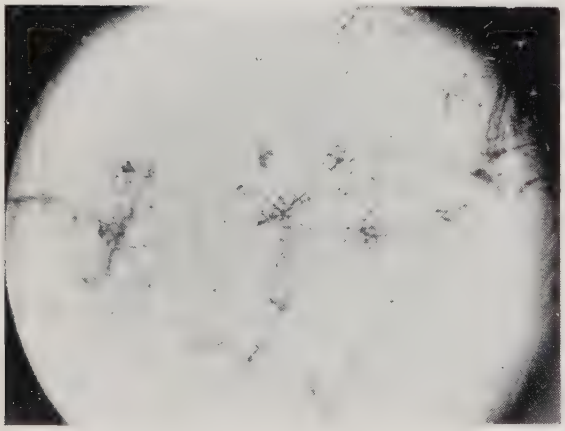

Fig. 4. *Conchocelis*-phase of *Bangia fusco-purpurea* (DILLWYN) LYNGBYE growing in calcite. ×60. Photographed on March 27, 1955 after 27 days cultivation.

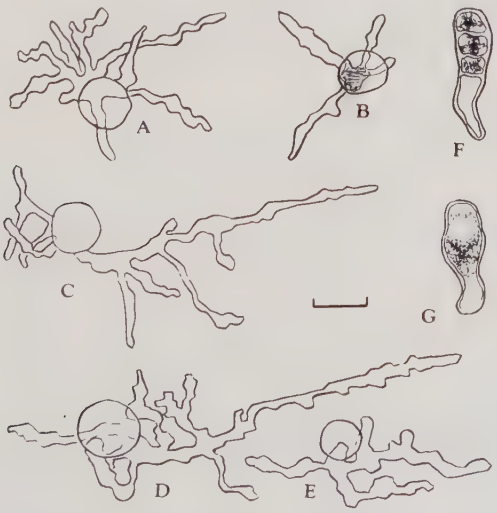


Fig. 5. *Conchocelis*-phase of *Bangia fusco-purpurea* (DILLWYN) LYNGBYE growing in calcite, cultured for 10 days. A～C : Normal germination. D・E : Right-angled branching. F・G : Young plants growing upright on the calcite surface. Scale 15 $\mu$.

直立藁体になったものが単胞子であるかどうかはたしかめることができなかった。糸状体と直立藁体が同時にあらわれる現象は，基物が方解石のばあいのみならず貝殻のばあいにも同様にみとめられた。

4月5日に播種したものは，4月15日には第5図にみられるような形態になって穿孔した。直立藁体になったものは2～3細胞に分裂していた（第5図F・G）。

劈開の方向と関係があるとおもわれる走角のある枝は，アサクサノリ糸状体のばあいよりウシケノリ糸状体のばあいに多くみられた（第5図D・E）。長期間培養をすると ウシケノリ糸状体のひろがり 全体が方解

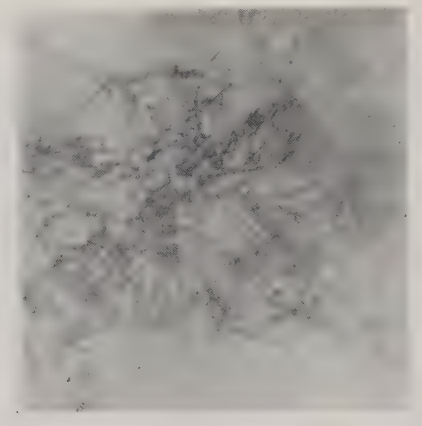

Fig. 6. Square colony of *Conchocelis*-filaments of *Bangia fusco-purpurea* (DILLWYN) LYNGBYE in calcite showing the branch growth influenced by cleavage planes of calcite. Photographed on May 26, 1955 after 51 days cultivation. ×60.

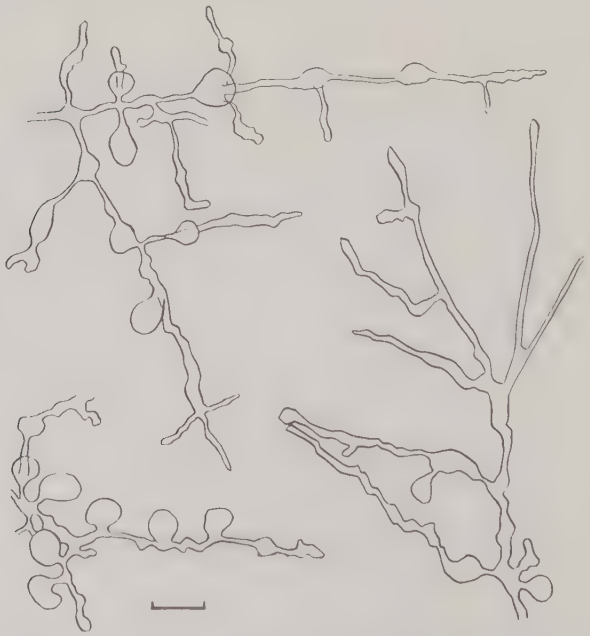

Fig. 7. *Conchocelis*-phase of *Bangia fusco-purpurea* (DILLWYN) LYNGBYE growing in calcite. Note the bell-shaped inflations. Cultured for 31 days. Scale 15 $\mu$.

石の劈開の方向に左右されて，方形に近い糸状体斑をつくる傾向がみられた（第6図）。

5月10日の観察では，第7図にみられるように，比較的生長の初期において，枝の先端および基部の一部が鈴状にふくれている形態のものが多くみられた。これは将来単胞子嚢* になるものかどうかあきらかでない。同じ方解石中でもアサクサノリ糸状体のばあいにはあまりこうした傾向はみられない。この方解石中に生育したウシケノリ糸状体は，その夏の高温にもあまり枯死することなく秋まで生存し，晩秋にはその表面に直立したウシケノリ葉体が生じていたのが観察された。これはおそらくウシケノリ糸状体に生じた単胞子が発芽したものであろう。

4月5日にカキ殻に穿孔したウシケノリ糸状体は，10日後に観察すると，方解石中のような枝の圭角はみ

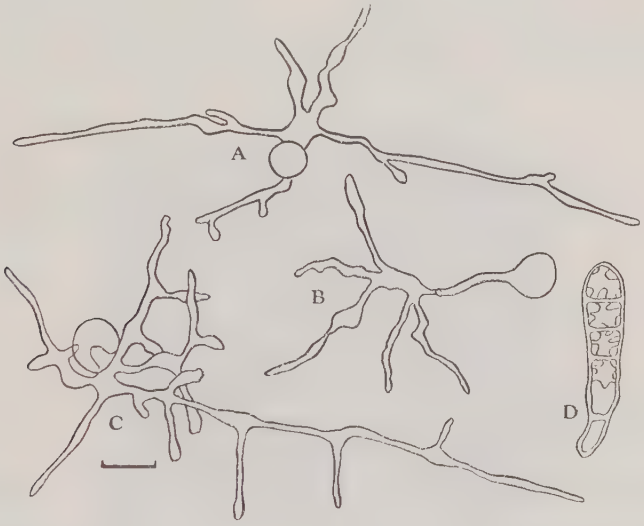


Fig. 8. *Conchocelis*-phase of *Bangia fusco-purpurea* (DILLWYN) LYNGBYE growing in oyster shell, cultured for 10 days. A～C : In oyster shell. D : Plant growing upright on the shell surface. Scale 15 $\mu$.

られない（第8図）。しかし培養がながくなると，方解石中でみられると同様な鈴状にふくれた部分が生ずるのが観察された。DREW (1958) は，自身が観察した second type の spore の胞子嚢が，このようなウシケノリ糸状体に生ずる膨大部と関係があるのではないかとみている。

またウシケノリ糸状体のしめす色について，DREW (1958) はナポリの材料では greenish blue であるとのべているが，筆者は，ウシノケリ糸状体の穿孔している貝殻や方解石の面は淡紅色をしめしていることを観察した。

## B. 石灰石中の生長

1955年3月24日に石灰石上で発芽したアサクサノリ糸状体は，その中に穿孔して生長した。供試した石灰石は，スライドグラスにはりつけてうすくし，透過光線による顕微鏡的観察が可能なていどにしたが，それでも充分透明にはなりにくかった。したがって微細な点は不明であるが，21日後にはだいたいにおいて貝殻中の生長とかわりがない様子をしめした（第9図）。

右田・太田（1957）は同様の実験をおこない，石灰石中に生育したアサクサノリ糸状体から採苗することに成功している。このことは糸状体が石灰石中で，貝殻中と同様に生長し成熟しうることをしめしている。

* 第1章第7節参照。

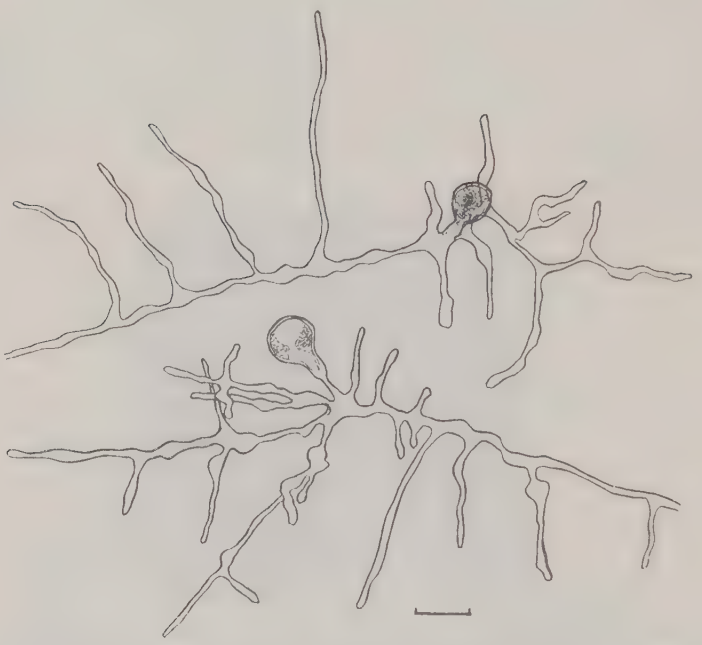

Fig. 9. *Conchocelis*-phase of *Porphyra tenera* KJELLMAN growing in limestone. Cultured for 21 days. Scale 15 $\mu$.

またこのことは自然の海中において，石灰岩も糸状体の基物になりうる可能性があることを意味している。

## C. セメント中の生長

セメントがふつう石灰石からつくられることは周知のことである。上述のように糸状体は石灰石中にも穿孔しうるから，石灰石を原料としたセメントにも穿孔しうる可能性が考えられる。このことをたしかめるために二，三のセメントを基物の原料として実験をおこなった。セメントとしてポートランドセメント，白色ポートランドセメント* をもちいた。それらを適当な量の水でといてスライドグラス上にうすくぬりつけ，乾燥させたものを水道の流水中に数日間ひたし，最初に滲出するアルカリ性物質の影響を少なくする処置をとった。播種は常法により行ない，実験は1958年12月以降におこなった。

## 結果および考察

1958年12月6日にアサクサノリを母藻として播種されたものは，約1カ月後には白色セメント中にあきらかに糸状体の穿孔したことが顕微鏡観察によってみとめられた。そのころにはセメント面は貝殻中の糸状体のしめす色とよく似た色を呈していた。またマルバアマノリ *Porphyra suborbiculata* KJELLMAN を材料にして1959年1月18日に実験をはじめたものにも同様の穿孔をみとめた。ついで3月6日にウシケノリについておこなったものも同様であった。

これらの白色セメント中に穿孔した各種糸状体の形状は，貝殻中とまったくことなって，セメント中全面

* 白色ポートランドセメントの組成[14]（%）

| CaO | $SiO_2$ | $Al_2O_3$ | $SO_3$ | MgO | $Fe_2O_3$ | 灼熱減量 |
|---|---|---|---|---|---|---|
| 65.0 | 23.7 | 5.2 | 1.8 | 1.1 | 0.77 | 1.6 |

に糸状に生長することはなく，セメントを構成しているある種の粒子中にまるく団塊状になって穿孔している状態がみられた。

このような糸状体の細部については，白色セメントがどのようにうすくぬりつけた状態であっても，かなり不透明であるために観察がむつかしく，そのままではっきりしたことがつかめなかった。しかし，おそらくセメントを構成するある種の粒子およびその集団の中に生育するために，糸状体が団塊状をしめすものとおもわれる。この糸状体が穿孔している粒子はおそらく CaO か，あるいはそれが $CO_2$ を吸収して生じた $CaCO_3$ の粒子であろう。

これらセメント中に穿孔した糸状体のうち，マルバアマノリとウシケノリの糸状体はその後も生存をつづけて，1960年7月8日の観察でもセメント面があきらかに紅色をした糸状体斑がみられた。

これらセメント中の糸状体の細部を観察するために，糸状体斑が存在するセメント片を Pérényi の溶液で脱灰し検鏡した結果，あきらかに糸状体とおもわれるものが観察されたが，予想どおり貝殻中に穿孔した糸状体とは相当ことなる形態をしめすことがわかった。

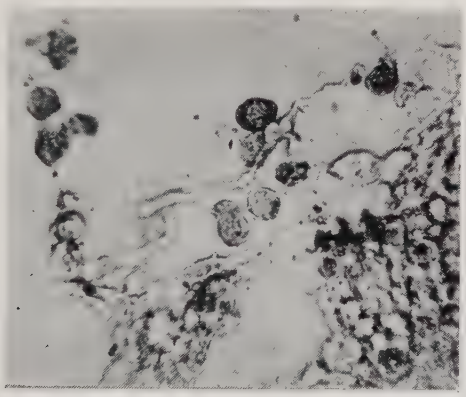

Fig. 10. Modified shape of *Conchocelis*-phase of *Bangia fusco-purpurea* (DILLWYN) LYNGBYE grown in cement mortar of white Portland cement. Taken out of the substratum by decalcification. ×500.

すなわち，ウシケノリ糸状体のばあい第10図にみられるように，糸状の部分が少なく，膨大部の多い団塊状の形態をしめし，貝殻中のような複羽状をしめさない。ウシケノリ糸状体は貝殻中でも膨大部の多い形態をしめすが，セメント中のばあいはなおこの傾向がはなはだしいようである。

セメント中のマルバアマノリおよびアサクサノリの糸状体を脱灰してみても，ほぼ同様の観察結果がえられた。

白色ポートランドセメントを海水，0.01モル第1燐酸ソーダ，0.01モル硝酸ソーダの各溶液でかためたものについても，ほとんど同じような穿孔状態がみられた。

ふつうのポートランドセメントは，灰黒色でまったく穿孔の有無が観察できなかった。

白色セメント中の糸状体からの採苗にはまだ成功していないが，この採苗が可能であるとすれば，イワノリ類の増殖事業におけるセメント張の位置を低潮線下にすることによって，そこが永久にイワノリ類糸状体の基盤となりうることも予想される。

## 要　　結

1．方解石中で生長したアサクサノリ糸状体の形態は，貝殻中のものと全般的にあまりかわらないが多少の差はみられる。

2．方解石中においては，アサクサノリ糸状体の枝の縁辺がなめらかでなく，主角を生ずる傾向がある。
3．この主角は方解石の劈開の方向と関係がある
4．ウシケノリ糸状体においても，方解石中においては枝に主角を生ずる傾向がみられる。
5．ウシケノリ糸状体は，方解石および貝殻中において鈴状のふくれた枝を生ずる傾向がある。
6．アサクサノリ糸状体は石灰石中でも穿孔生長し，形態は貝殻中のばあいとあまりかわらない。
7．白色ポートランドセメントを水で固めたものの中にも，糸状体が穿孔するが，その糸状体斑の外観的形態は貝殻中のばあいとかなりことなった様子をしめす。

## 第5節　いわゆる“サメ肌”について

糸状体を培養中にしばしば“サメ肌”とよばれる現象がおこる。これは培養がすすんで糸状体がかなり生長した貝殻の面に，微小な突起が一面に生ずる現象をいう。このような突起は糸状体の培養期間が長くなるとともに，しだいにザラザラとした感触をしめすようになる。一部では“サメ肌病”とよばれているようである。

1958年12月以来，アサクサノリ糸状体を培養してその垂直的生長の観察をおこなったさいにも，やはり“サメ肌病”状の現象が生じたので，それについて観察をおこない，その結果に対していろいろ考察をした。

### 材料および方法

貝殻上にできた突起物をくわしく知るために，第1章でのべた方法で問題の部分を切断し，その断面が観察できるプレパラートをつくって顕微鏡観察した。サンプリングはアサクサノリ糸状体の培養系列中（1958年12月6日，12月18日，アコヤ貝殻に播種）から，比較的“サメ肌”状のひどいものをえらんでおこなった。

### 結　　果

貝殻面に突起があきらかにみとめられはじめたのは，培養日数100日目のサンプルからである。その貝殻の突起の多い部分をえらんで断面をつくり観察すると，あきらかに“サメ肌”状突起の切断面がみとめられる。この突起は比較的ととのった半球状である（図版Ⅵ A・B）。これらは播種をしたがわの貝殻内面だけでなく，殻皮側にも生じている（図版Ⅵ B）。これらの突起と突起との間隔はまちまちであるが，培養期間が130日（図版Ⅵ C・D），150日（図版Ⅵ E・F）とながくなるにつれて，たがいに隣接して多発するようになる。そしてたがいに融合してかたまりをつくっているところも生じてくる（図版Ⅵ D・E）。そして，しだいに基部面積の大きい高原状の突出（図版Ⅵ F）になってゆくようである。ほぼ半球状をした突起の基部の直径は，100日目のもので100～150μに達する。150日を経過したものでは200μ以上に達している（図版Ⅵ E）。興味深いのは，これらの突起中に多かれ少なかれ糸状体の延長のようにみえる構造が存在していて突起の上面に達しているようにみえることである。形は比較的簡単で真直なものからたがいにからみあって複雑になったものまで，いろいろである。

この糸状体状の構造は，ほとんどの突起部にみられるが，中には存在していないようにみえる突起もある。なお，プレパラートをよく観察すると，突起部の断面には同心円状のリングがはっきりとみとめられるものが多い（図版Ⅵ C）。

このリングと糸状体様の構造の存在は，貝殻面にある糸状体の末端を中心として，突起がだんだんと生長し，それにつれて糸状体も延長していき，ちょうど噴火山の発達のような経過で突起部をつくられることを想像させる。

一方，1958年の1月に播種してから培養をつづけていたカキ殻にもこのような突起が多くできていた。すなわち“サメ肌病”にかかっていたわけであるが，べつに表面のざらざら以外には異常なく生存していた。このカキ殻の“サメ肌”部分の断面を同様にして観察すると，アコヤ貝殻のばあいと少しもかわらない構造がみられた（図版Ⅵ G・H）。すなわち，半球状の突出部のなかを貫通する糸状体様の構造も，同心円状の

リングもみられる（図版ⅦG）。つまり貝殻の表面にあらわれる突出は，アコヤ貝殻とカキ殻の両方のばあいをくらべてみて，形態的には本質的な差がないといえよう。

貝殻上だけでなく，器底にもザラザラした白色の沈着物がみられることがある。とくに，長いあいだ糸状体を培養したガラスバットの底などにこれができていることを後になって知ることが多い。この実験では，培養後130日ぐらいで気がついた。ガラス上にできたこのような沈着物を顕微鏡観察すると，小さなトゲ状の結晶が金平糖状に集合したようになっていることがわかる（図版ⅦA）。これらの小さな結晶があつまって大きくなり，半球状になったと思われるものもある（図版ⅦB）。

## 考　　察

上述の形態観察から推すと，いわゆる“サメ肌”の成因については，つぎのような考えもなりたつものとおもわれる。すなわち，糸状体が貝殻の表面直下の層で濃密に分布して代謝が旺盛になると，最初の果胞子から発芽体が穿孔した場所，またはのちになって糸状体が貝殻面に達して外界と連絡したとおもわれる場所などからカルシウムが分泌され，その近辺でただちに飽和析出する。そしてそれらの周囲に沈着しながら，しだいに大きさをまして“サメ肌”になるとも思われる。突起部のなかに，糸状体様の構造と同心円状リングのできる現象は，上のように考えれば無理なく説明できる。

この糸状体から分泌されて析出沈着する物質は，貝殻上の突出部ばかりをけずりとったものや器底上の析出物が酸によって容易にとけることから，カルシウムが主成分と考えられる。

このように析出されるカルシウムは，糸状体が貝殻中で先端生長するさいに，炭酸カルシウムを溶解して生じたものと考えれば，“サメ肌”を構成する比較的多量なカルシウム分の起原の説明として矛盾はないとおもわれる。

器底の析出物は，はじめから海水中に溶存していたカルシウムが析出したものか，糸状体から分泌されるカルシウム分の量が多くて貝殻面の分泌口の周囲に沈着するよりさきに拡散して，貝殻表面からはなれた器底で析出したものかあきらかでない。

一方“サメ肌”の成因に関して右田（1959）は，糸状体を培養している海水の pH 値の上昇がその主な原因であるとしている。そして糸状体のみでなく緑藻類を培養中にも海水 pH 値の上昇によって“サメ肌”状析出物を生ずることもみている。

このような事実を考えあわせると，“サメ肌”の成因は単純なものでなく，海水中に既存のカルシウムや糸状体から分泌されるカルシウム，pH 値の変化などの間の複雑な関係によって生ずる過程とおもわれるから，この問題に関してはなお検討の余地がある。

以上の考察からもあきらかなように，いわゆる“サメ肌”の現象は，いままで一部で考えられたようなひどく病的なものとはおもわれない。しかし燐酸塩をくわえて培養したものは，あまり“サメ肌”にならないか，尿素をくわえて培養するとこの症状がひどいといわれている[38]から，糸状体の代謝のアンバランスが“サメ肌”の成因に関係しているとおもわれるので，“サメ肌”を生ずるような環境は，やはり糸状体にとってあまり好条件とはいえないようである。しかし，多くの突起部には，糸状体の延長と思われる構造があって，表面に達しているところもあるようにみえるが，これが事実ならガス代謝や塩類の拡散には大して支障がないと思われる。

## 要　　結

1. 糸状体培養中の貝殻の表面には，しばしば“サメ肌”とよばれる現象が生ずる。
2. この“サメ肌”状突起の断面をみると，同心円状層のある半球状の突起である。
3. 突起部の中にはしばしば糸状体様の構造があり，その表面に達しているようにみえる。
4. 長期培養によって，糸状体が下面（すなわち殻皮）に達したものでは，両面にこの突起が生じているものもある。

5．カキ殻とアコヤ貝殻とでは，生じた“サメ肌”に本質的な差がみとめられない。

6．貝殻上のみでなく，培養器底にも析出物が生ずる。

7．“サメ肌”状突起やガラス上の析出物は，カルシウムが主成分であると考えられる。

## 第6節　イワノリ類糸状体の生長

アマノリ類の種類によって，その糸状体の形態がことなるものかどうかは興味ある問題とおもわれるし，また，じっさいに海底の貝殻などに穿孔している糸状体の形態から，その母藻の判定ができれば実用的にも役立つものとおもわれる。

いままでの研究では，黒木（1953a）が，アサクサノリ，マルバアマノリ，チシマクロノリ，ウツプルイノリについて観察した報告がある。これによると，それらアマノリ類の果胞子はすべて発芽管をだして発芽し，貝殻などの内層に侵入し生長して糸状体になるが，それら各種の糸状体のあいだにおける形態の差は，その糸状体斑の大きさ・色・膨大部の多少・また膨大のていど・関節の長さ・単胞子囊枝の太さ・単胞子の大きさなどにいくらかみられるようであるが，識別はきわめて困難である，としている。

この結果からみて，糸状体の形態からその種類を識別することはかならずしも容易でないと思われる。しかし，これまでおこなわれてきた貝殻の表面からの観察にくわえて，その断面をつくって糸状体の垂直的生長をしらべれば，またなんらかのてがかりがえられるものと考え，アマノリ類のうちいわゆるイワノリ類とよばれるもの数種とウシケノリ類2種についてその糸状体の垂直的生長を観察した。

### 材料および方法

| | |
|---|---|
| マルバアマノリ | *Porphyra suborbiculata* KJELLMAN |
| クロノリ | *Porphyra okamurai* UEDA |
| ウツプルイノリ | *Porphyra pseudolinearis* UEDA |
| オニアマノリ | *Porphyra dentata* KJELLMAN |
| ウシケノリ | *Bangia fusco-purpurea* (DILLWYN) LYNGBYE |
| フノリノウシゲ | *Bangia gloiopeltidicola* TANAKA |

の6種についてその糸状体の培養をおこなった。マルバアマノリ，オニアマノリ，フノリノウシゲは下関市吉見地先の海岸で採集したものであるが，オニアマノリはイワヒゲ上に，フノリノウシゲはフクロフノリ上に着生していたものである。クロノリ，ウツプルイノリは長門市仙崎で，ウシケノリは下関市安岡海岸でそれぞれ採集したものである。

播種の日時は，下記のとおりいずれも1959年1～3月中である。マルバアマノリ－2月10日，クロノリ－2月1日，ウツプルイノリ－2月19日，オニアマノリ－2月10日，ウシケノリ－2月21日および3月6日，フノリノウシゲ－1月29日。

基物はアコヤ貝殻である。垂直的生長の観察方法は前記とまったくかわりがない。また同時に水平方向のプレパラートもつくって観察した。

培養は室温による室内培養で室内散光のもとにおこなった。観察はだいたい3月下旬あるいは4月下旬と8月下旬の2ないし3回にわたってつくったプレパラートについておこなった。

### 結　　果

**マルバアマノリ**：4月27日まで76日間培養したものは，図版Ⅷ A・B にみられるような生長をしめした。水平方向の生長（図版ⅧA）はアサクサノリのばあいとくらべて特別にかわりがみられない。しかし垂直方向の生長（図版ⅧB）からみると，貝殻の表層における水平的生長にくらべて貝殻内層における発達がわるいようである。すなわち，アサクサノリ糸状体では貝殻内層でも旺盛な生長をしめすのにくらべて，マルバアマノリのばあいは，内層における枝の伸長がおとる傾向がある。この傾向は8月29日まで200日培養したも

のについてもかわりがなかったが，このような枝は200日もたつと厚さ約 800 μ の貝殻の下面に達して，その近辺で水平方向に発達しているところもみられる。

**クロノリ**：2月1日から4月22日まで80日培養した糸状体について，その水平方向の形態（図版Ⅶ C）を観察すると，その枝には小さい屈曲が多い。垂直方向の生長（図版Ⅶ D）は，マルバアマノリのばあいとよく似た傾向をしめす。

また，3月12日と8月30日につくった標本からも，やはり上にのべたような傾向が観察された。なお8月30日には，斜め下にむかう枝の一部が厚さ約850 μ の貝殻の下面に達している状態が観察された。

**ウツプルイノリ**：4月30日まで70日間培養した糸状体は，水平方向（図版Ⅶ E），垂直方向（図版Ⅶ F）ともに，一方向にしだれたような形をしめしていることが多い。このような形状は，アサクサノリ，マルバアマノリ，クロノリのばあいとくらべて，やや特徴的である。

8月28日の観察では，やはり厚さ 700 μ 前後の貝殻を貫通した枝が下面に達している様子がみられたが，下面ではアサクサノリのばあいのようには発達していない。

**オニアマノリ**：2月10日に播種してから29日に観察すると，図版Ⅶ G・Hにみられるようにあまり特徴的な点はみられない。そして200日間の培養では800～900 μ 前後の垂直的生長をした枝がみられた。一般にイワヒゲ上に着生するアマノリ類は小型であるが，その糸状体斑も小型な傾向がみられる。

**ウシケノリ**：2月21日から4月22日まで60日間培養した糸状体の水平生長は，図版Ⅶ Iにみられるように，アマノリ類の糸状体にくらべて直線的な生長をする傾向がみられる。膨大部もアマノリ類より大きいようである。このことは方解石中で生長したウシケノリ糸状体に膨大部が多いことと一致している。

3月6日から4月22日まで培養したものの垂直方向の生長（図版Ⅶ J）をみると，この方向への生長は，アマノリ類の糸状体のばあいより貧弱である。すなわち貝殻の表面直下の層で水平的にひろがって繁茂するていどにくらべて，貝殻内層にむかう枝が少ないようである。3月6日から8月23日まで培養したものについてみてもこの傾向にかわりがない。

**フノリノウシゲ**：この糸状体は，ウシケノリの糸状体にくらべて全体に小型である。

4月24日まで60日間培養したものについて水平方向の生長を観察（図版Ⅶ K）すると，膨大部が比較的大きいことがめだつ。

垂直的方向の生長（図版Ⅶ L）は，フノリノ糸状体とおなじく下層にむかう枝が表面直下の繁茂の状態にくらべておとっているようである。

## 考　　察

以上の結果からみて，やはり黒木（1953a）のべているように，糸状体はその種類のあいだにみられる形態の差が水平的にも垂直的にも少なく，やはり識別がむずかしいようである。もちろん，それぞれの種類の糸状体は，よく観察すればいろいろな点に特徴がみられるが，これらの形態の差が種類に固定して不変なものかどうかもたしかでない。培養の条件によっては，同一種の糸状体でもその形態がかなり変化するようである。とくに水平方向においては光のくる方向に生長する傾向が生長の初期にみられることがあるので，しだれるような形態も，種特有のものか光の影響かあきらかでない。

また，穿孔する基物の差によっても形態にあるていどの差がみられるようである。このことはいろいろな種類の貝殻にアサクサノリの糸状体を培養した実験の結果（第1章第3節）でもあきらかである。したがってカキ殻のばあいと，この研究におけるアコヤ貝殻のばあいにも多少の差がみられるようである。

このように，糸状体の形態がしめす種類の差はあまりはっきりしたものではないが，少なくともつぎのようなことはいえるようである。すなわち，アサクサノリ糸状体のばあいにくらべて，イワノリ類の糸状体のばあいは，その垂直方向に生長する枝は伸長のていどがわるくあまり繁茂しない。このことはウシケノリ，フノリノウシゲでも同様であって，貝殻表層の繁茂にくらべて内層ではあまり繁茂しない傾向がみられる。ウシケノリ，フノリノウシゲではアマノリ類の糸状体よりやや膨大部が大きく，特徴的である。

## 要　　結

1．アマノリ類糸状体の種類のあいだにおける形態の差は，水平方向にも垂直方向にもきわめて少なく，識別は困難である。

2．イワノリ類糸状体，ウシケノリ類糸状体の貝殻内層における垂直的生長は，アサクサノリ糸状体にくらべると貧弱である。

3．ウシケノリおよびフノリノウシゲ糸状体は膨大部がやや大きく，他のアマノリ類糸状体にくらべてやや特徴的である。

## 第7節　各種単胞子嚢枝の断面観察

糸状体が成熟して生殖細胞をつくるばあい，その枝の一部が膨大して太くなり，そこにしきりが生じて中に一種の胞子がつくられることは周知のとおりである。このような膨大して中に胞子を生ずるような太い枝のことを，黒木（1953a）は単胞子嚢枝（monosporangial branch）といい，また DREW（1954）はこれを他の呼称でよぶよりも，さしあたり fertile cell-row と称したほうがあたりさわりがないといっている。しかし便宜上ここでは単胞子嚢枝と称することにした。

このような単胞子嚢枝のできかたについてもすでにいろいろ観察があるが，貝殻の内層内についてはまったく知見がなく，表面観察による推測しかおこなわれていない。

このような点をしらべる目的で，1958年12月から培養をはじめたアサクサノリの糸状体をはじめとして，1959年1月から培養をはじめた各種アマノリ類およびウシケノリ類の糸状体に1959年8月以降になっていわゆる単胞子嚢枝が生じた。そこでこれらをいままでもちいてきた方法で貝殻の断面をつくることにより，その垂直的方向の形態をあきらかにした。

### 材料および方法

供試材料はすべて前節のものとおなじであるが，フノリノウシゲ糸状体は途中で枯死したのでこれを除外した。また方法についてもまったくかわることがない。

培養は，アサクサノリ糸状体について1958年12月にはじめた以外は，すべて1959年1月からその年末にかけておこなった。したがってとくにしるさないかぎり，文中の日時は1959年の日時である。

### 結　　果

**アサクサノリ**：この実験においては，アサクサノリ糸状体にいわゆる単胞子嚢枝ができる時期は，イワノリ類のばあいにくらべてかなりおそくその数も少ない傾向がみられた。すなわち，9月下旬から10月上旬になってようやく一部のものにその発達がみられたにすぎなかった。この原因についてはあきらかでないが，培養条件や基物としたアコヤ貝の性質にも関係があるのではないかと思われる。

1958年12月6日に培養をはじめて翌年10月3日に観察したもののうちには，図版Ⅸ A・B のように表面直下の層中で発達した単胞子嚢枝と思われる太い枝がみられた。しかし，ふつう播種した側の表面直下の層よりも，むしろ糸状体が貝殻を貫通して反対側の稜柱層に達して，そのなかで発達しているばあいが多くみられた（図版Ⅸ C）。

このように播種した側であまり太い枝がみられないことについて，そこでは糸状体の繁茂がはなはだしく単胞子嚢枝の発達する余地が少ないこと，また同じ理由で観察も困難なことなどが原因と考えられる。

単胞子嚢のあり方で面白いことは，貝殻の下面（外面）に近い稜柱層と真珠層のさかい目から内層の真珠層の方に単胞子嚢枝が発達したばあいがみられることである（図版Ⅸ D・E）。ふつう単胞子嚢枝は，少なくともその一端が貝殻の両面に達するていどの表層中に存在しているのであるが，このばあいは貝殻の下面（外面）からはなれて稜柱層をへだてた層中に存在しているようにみえる。しかしよく観察すると，このよう

なところは真珠層と稜柱層のあいだにわずかでもすきまがみられる（図版ⅨE）。すなわち単胞子嚢枝の一端は，やはり外界に接しているものとおもわれる。単胞子嚢枝がどこに存在するにせよその形や長さおよび太さなどはかなりまちまちである。

一般にアサクサノリのばあいは，あとでのべるイワノリ類のばあいにくらべて，その太さがやや太く，長さは短かい傾向がみられる。その例として２月26日から９月21日まで培養したものでは図版ⅨFにみられるような太さ約８～10μ，長さ約80μの単胞子嚢枝が生じていた。このばあいは播種した側に生じていた。

1958年12月６日から翌年11月16日まで培養したものでは，いわゆる“サメ肌”状突起のなかにも単胞子嚢枝とみられる太い枝が生じているのが観察された（図版ⅨG）。

また別に３月29日から11月16日まで培養したものを観察したが，これは培養の開始がおそかったのでその繁茂のていどがわるく，したがって単胞子嚢枝の表面観察ができた（図版ⅨH）が，やはり稜柱層のなかにみられるばあいが多かった（図版ⅨI）。

約１年間（1958年12月６日～59年12月17日）培養したものでも，単胞子嚢枝のできる数はあまり多くなかった。またやはり播種面より反対側の面に近く生じているばあいが多く（図版ⅨJ～M），それも稜柱層のなかに存在していることが多かった（図版ⅨL・M）。

**マルバアマノリ**：この糸状体には，７月下旬にすでに単胞子嚢枝らしい太い枝が生じていたが，８月下旬には相当の大きさに達していた。すなわち２月10日に播種し８月29日に処理して観察したものでは図版ⅩA～Dのようである。これでみるとマルバアマノリの単胞子嚢枝はアサクサノリのばあいよりやや細く７～８μであるが長さは逆に長く200μに達している。マルバアマノリのばあいは，播種した側の面にも反対側の面にも同様に，単胞子嚢枝ができていることが多かった。

10月２日の観察ではさらに長いもの（280μ）がみられる（図版ⅩE～G）。

プレパラートのつくりかたによって，そのような太い枝の内容がなくなっているようにみえるところもあるが，それらの枝が表面に達していることがあきらかにみとめられるところがあった（図版ⅩC・F）。

11月13日（図版ⅩH・I），12月14日（図版ⅩJ・K）の観察でもほぼ同じようなことがみられた。

**クロノリ**：２月１日から培養をはじめたクロノリの糸状体には，８月30日にはあきらかに単胞子嚢枝の形成がみられた（図版ⅪA～C）。

その形はいろいろであるが，なかにはアーチ状になったもの（図版ⅪB）もみられた。これには内容がぬけた管状の部分がみられるが，このばあいもその一端または両端が表面に連絡しているようにみえる。まっすぐに内層にむかうものももちろん観察された（図版ⅪC）。

11月13日の観察（図版ⅪD），12月15日の観察（図版ⅪE）でもとくにかわりがみられない。12月15日のものでは最長250μの長さに達している。

**ウツプルイノリ**：単胞子嚢枝の形成がマルバアマノリやクロノリの糸状体のばあいにくらべて比較的少なかった（図版ⅪF～H）。

２月19日から８月28日まで培養したものには，ごく小さいものがみられた（図版ⅪG）が，12月15日には相当な長さ，すなわち280μぐらいまで内層にのびたものがみられた（図版ⅪH）。

**オニアマノリ**：２月10日に培養を開始したものには７月下旬にすべて単胞子嚢枝とみられるものが形成されたが，８月にはさらにはっきりとみとめられるようになった。その形状はとくにクロノリやウツプルイノリなどとかわることがない。たとえば11月17日に固定したものを図版ⅪI・Jにしめす。

**ウシケノリ**：ウシケノリの糸状体は，培養がながくなるとその水平方向に生長した枝に膨大部が多くなることについてはすでにのべたが，このような膨大部の多い枝は垂直的に内層方向に生長した枝にもみられることがこの実験であきらかにされた。すなわち２月21日に播種して11月13日に固定したものをしめした図版ⅪK～Mから，念珠状の枝が水平的に生長したものにも垂直的に生長したものにも存在することがわかる。アコヤ貝殻を基物にしたばあいにはこれ以外のものは観察されなかったが，1960年３月１日からタイラギ殻

を基物にして培養をはじめた糸状体を，10月6日に観察したところ，このような念珠状の枝の他にアマノリ類のものとほとんどかわりのない単胞子嚢枝の存在がみとめられた。Nはその貝殻の断面観であり，Oは平面観である。この結果からみて，単胞子嚢枝の形態においても，アマノリ類とウシケノリ類のあいだに大きな差はみとめられないといえよう。しかしウシケノリ類においては，貝殻によって多少の差はみられるが上記のような念珠状の枝が内層方向に生長した枝にもみられることが特徴のようである。

このような念珠状の形状は，成熟するまえのウシケノリの糸状体にすでにみられる膨大部の多い形態となんらかの関係があるようにおもわれる。ことにウシケノリ糸状体が方解石中で生長するときに，その枝に膨大部がとくに多いことをすでにのべたが，このような点はウシケノリ類の糸状体がもつひとつの特徴とおもわれる。

## 考　　察

一般にすべての種類において，単胞子嚢枝叢が貝殻の表面直下の層に多くみられることは今までおこなわれた平面観察の結果とかわらないが，その枝の一部は内層方向にもかなり長く伸長することはあきらかである。この内層方向にむかう単胞子嚢枝はイワノリ類糸状体のものはアサクサノリ糸状体のものより長い傾向がみられる。

単胞子嚢枝叢が貝殻の表面直下に存在しないで，稜柱層と真珠層のさかい目から内層の真珠層がわに発達した例がアサクサノリのばあいにみられた。すなわち外界と直接連絡していないようにみえる単胞子嚢枝がみられたが，このようなばあいはそれが存在しているところの真珠層と稜柱層との結合がゆるく，そのあいだにすきまがあってはなれていることが観察されたので，単胞子嚢枝の少なくとも一端は，直接外界の海水に接していることが想像される。

貝殻の両面からはなれた中層部では，いくら糸状体が発達していても太い枝が外界と連絡することなく，単胞子嚢枝が形成されたようなばあいはまったくみられなかった。いわゆる“サメ肌”状突起のなかにもあきらかに単胞子嚢枝の初期とみられる太い枝がみとめられた。

ウシケノリでも，アマノリ類の単胞子嚢枝とほとんどかわりのない単胞子嚢枝がみられるから，単胞子嚢枝の形態による判別は困難であるが，ウシケノリ糸状体には膨大部をもつ枝が多いことが特徴と思われる。

単胞子嚢枝は糸状体が貝殻を貫通して達した反対側の面にも生ずる。ここに長く培養して密に糸状体が繁茂したばあいには，この反対側の面やその稜柱層中に多く形成された。とくにアサクサノリ糸状体でこの傾向がつよい。また単胞子嚢枝は稜柱層のなかではやや形がことなり，稜柱層のたて縞理に影響されて，細ながくなる傾向がみられる。

この実験においては，アサクサノリとウシケノリの糸状体では，単胞子嚢枝の形成が他のイワノリ類のばあいよりかなりおそかった。すなわち，イワノリ類でははやいものは7月にすでに形成された。

このような単胞子嚢枝の形成の難易は，糸状体の培養条件のみならず，貝殻の種類にも関係があるようにおもわれる*。

また，単胞子嚢枝叢の一部の枝が貝殻内層に達する距離も貝殻の種類によって差がみられるようである**。

貝殻以外のものを基物にしたばあいの単胞子嚢枝の形成について一，二の観察をしたので，この節で附記することにした。

基物として方解石をもちい，1960年2月22日から培養をはじめたアサクサノリ糸状体に，9月8日の観察であきらかな単胞子嚢枝の形成がみられた。第1図は表面からの観察であるが，その形態や太さなどは貝殻が基物であるばあいの単胞子嚢枝とほとんどかわらず，なかに塊状をした紅色の色素体がみられることも同

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*　カキ殻とアコヤ貝殻とを基物にして，アサクサノリとウシケノリの糸状体を平行して培養したばあい，アコヤ貝殻中では単胞子嚢枝の形成が両種ともおそく，かつ少ない傾向がみられる。

**　イワノリ類の単胞子嚢枝においては，一般にアコヤ貝殻中ではカキ殻中より内層深く達する傾向がみられる。

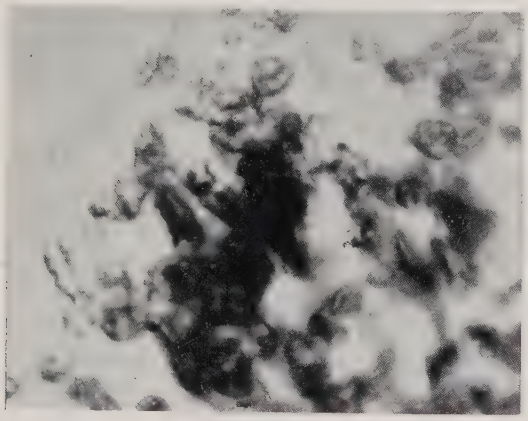

Fig. 11. Fertile cell-rows formed in the *Conchocelis*-phase of *Porphyra tenera* KJELLMAN which matured in the calcite. Photographed on Sept. 8, 1960. × 500.

様である。この単胞子嚢からの単胞子の放出もその年の10月25日にあきらかに観察された。

方解石以外では，大理石を基物にしてすでに右田・太田（1957）が糸状体を培養成熟させ，それからの採苗にも成功しているから，糸状体は貝殻以外の石灰性基物中でもかなり普遍的に成熟して単胞子嚢枝を形成しうるものとおもわれる。

## 要　　結

1. アマノリ類，ウシケノリ類の糸状体に形成される単胞子嚢枝叢のうち，一部の枝は貝殻の内層方向にむかって伸長し相当の長さに達する。
2. 内層方向にむかう単胞子嚢枝はアサクサノリよりイワノリ類のばあいに長い傾向がみられる。
3. ウシケノリの単胞子嚢枝もアマノリ類のものと形態において大差がみとめられない。
4. アコヤ貝殻の稜柱層中でも単胞子嚢枝が生じる。
5. いわゆる“サメ肌”状突起の中にも単胞子嚢枝が形成される。
6. 方解石のような貝殻以外の基物中でも，単胞子嚢枝が形成されうる。

## 第8節　単胞子嚢枝の生長過程と開口

単胞子が単胞子嚢から放出されるためには，当然貝殻表面に単胞子嚢枝が開口していなければならない。この単胞子嚢枝の開口については，わずかに山崎（1954a）の記述がみられるのみで，他にくわしい報告がみられない。一般に単胞子嚢枝の開口の確認は，糸状体が繁茂すると貝殻表面の観察では困難なことが多い。また貝殻断面の観察でも単胞子嚢枝の一端が表面に達しているらしいことはみとめられても，その開口状態については確認が困難である。したがって，このことをさらに精密な観察によってたしかめる必要を感じたので，従来の材料を精査しなおし，またあたらしく糸状体を培養して，その貝殻の断面作成をきわめて入念におこなったところ，二，三の点についてしることができたので，その結果についてのべる。

実験および観察は1960年３月以降である。

## 結　　果

表面観察による単胞子嚢枝の開口は，1959年２月１日に培養を開始し，210日後の８月30日に固定したウロノリ糸状体の単胞子嚢枝について確認された。この材料は比較的疎な生育をしていたので観察が容易であ

ったものとおもわれる。

図版XIIAにみられるように，クロノリ糸状体の単胞子嚢枝の開口は，ほとんど単胞子嚢枝の太さとかわらず，9〜12μていどの直径をもつ円孔である。

断面観察による単胞子嚢枝の開口は，1959年2月10日から11月17日まで培養した糸状体についてみとめられた。この糸状体はイシゲ上に着生していたアサクサノリとおもわれる種類を母藻にしてえられたものである。

図版XIIBにみられるように，あきらかに単胞子嚢枝が表面に達していて，その開口部の直径は単胞子嚢枝のそれとかわらないことが観察される。単胞子嚢枝の内容は，貝殻表面の開口部よりやや内方に収縮している。このことは上記の表面観察のばあいにもみとめられた。おそらく固定処理のためであろう。つぎに，このような開口を生ずるまでの単胞子嚢枝の生長過程をマルバアマノリの糸状体についてしらべた。

1960年3月1日から培養し，それに生じた単胞子嚢枝のごく初期の形成過程を貝殻断面により観察した。その経過をみると，6月14日にはすでに単胞子嚢枝の初期のものとおもわれるものが形成されている（図版XIIC・D）。これは長さ約25μの太い枝であって，貝殻表面から6〜8μないし20〜30μのごく表層に近いところから糸状体の側糸として発出しているが，この時期にはまだこの太い枝自体はどの部分も表面に達していない。

6月20日にはやや発達した単胞子嚢枝がU字型をしめし，その両端がそれぞれ表面から約15μおよび30μのところに存在する（図版XIIE）。このばあいも単胞子嚢枝はまだ表面に達していない

その後このような単胞子嚢枝の数がしだいに増加し，8月上旬には長さ約100μに達するものがあらわれ，また単胞子嚢枝の開口らしいものも表面観察によりみとめられる。

なお，糸状体が生育している貝殻の表面には，以上のような開口の他に，果胞子が最初に穿孔侵入するさいの穿入孔も存在するので，アサクサノリ果胞子をタイラギの真珠層に播種してえられた糸状体を材料にしてこれを観察した。

1960年3月1日に，昼光色螢光燈をもちい約800 luxの照度下で培養を開始し，3月7日に固定したものについての観察では，果胞子の発芽体の穿入孔は約5μの直径で果胞子の直径よりかなり小である（図版XIIF）が，穿入した直下で糸状体はかなり膨大している。

以上の結果から，糸状体の穿孔，単胞子嚢枝の形成，成熟，開口という過程を追うと，ノリの種類，基物および時期もそれぞれことなっているが，図版XIIはF，C，D，E，B，Aの順になる。

## 考　　察

以上の観察から単胞子嚢枝が貝殻表面に開口する時期は，単胞子嚢枝の形成の当初でもなく，また単胞子放出直前でもないといえる。すなわち，はじめ貝殻表面直下10〜30μていどの層に存在する糸状体の枝から，短かく太い単胞子嚢枝の起原が発出するが，それは貝殻表面に開口をもたない。しかし，このような単胞子嚢枝の起原が生長するにしたがって，貝殻内層方向に長さをまし，またその過程のどこかで表面に開口をもつにいたるものと考えられる。

マルバアマノリ糸状体のばあいは，6月下旬に単胞子嚢枝の起原を観察し，8月上旬にはその貝殻表面における開口をみとめている。またクロノリ糸状体では，8月下旬に固定したものについて，あきらかに単胞子嚢枝の開口をみとめている。このような開口の直径が，単胞子嚢枝の太さとほとんどかわらないものであることも，単胞子の放出の機構と関連して面白い事実と思われる。

なお，果胞子からの発芽体が最初に穿孔した穿入孔の大きさは，果胞子よりかなり小さく5μ前後である。

## 要　　結

1．単胞子嚢枝が貝殻表面に達して形成する開口は，単胞子嚢枝の太さとほとんど同じていどの直径を有する。

2. 単胞子嚢枝は，はじめ貝殻内層のごく表面に近い糸状体の枝の一部から発出し，しだいに内層にむかって長さをますとともに，表面にも達して開口を形成するものと思われる。
3. 果胞子の発芽体が穿孔した穿入孔は，直径約5μていどの小孔である。

# 第2章　ノリ糸状体の生長に関する生理学的研究

アサクサノリなどの糸状体は，貝殻等の石灰質中に穿孔して生長するという特異な生態をしめすために，その穿孔の機作をはじめとして，貝殻中における生長の機構，代謝，ガス交換などの生理上の問題に関して多くの関心がもたれていた。しかし，貝殻中に穿孔して生長するという興味ある点が，逆に実験の操作上いろいろな困難をもたらすためか，この方面の研究はなかなか進展しなかった。その主な困難は，実験上必要な量の糸状体を，貝殻からはなして大量に培養しがたいこと，したがって生重量が秤量できないことなどであろう。すなわち糸状体にはどこまでも穿孔基物である貝殻の問題がつきまとうため，研究が複雑になるものと思われる。筆者は1955年の春以来，いろいろな方法をもちいて糸状体の生長に関する研究を生理的に解明することにつとめてきた。もちろん上述のような方法論上の隘路も根本的に打開できたわけでなく，もちいた方法にも，えられた結果にもまだ問題は多いと考えられるが，今後の研究上の一応の出発点にはなりうるものと思われたので，本章においてくわしくのべることにした。

## 第1節　糸状体の穿孔生長

糸状体の生長においてもっともめだつ点は，貝殻などを基物にして，そのなかに穿孔し生長するということであろう。穿孔藻類としては *Gomontia* などの緑藻類やある種の藍藻類があるが，アサクサノリなどの糸状体のように顕著に穿孔生長するものは少ない。

このような糸状体の穿孔性の機序の一端にふれるために，まず生理的方面から解決のいとぐちをつかもうとした。そして最初に実験の対象として，糸状体の基物に対する選択性をとりあげた。

### A. 糸状体の穿孔基物

糸状体は，生物起原の石灰質だけでなく，鉱物性石灰質にも穿孔して生長しうることはすでに第1章第4節でのべたとおりである。このように無機物にも穿孔しうることがわかったので，石灰質以外の無機物に対しても穿孔できないものかどうかをしらべた。

一般に石灰質は貝殻や鉱物質のものも硬度がかなり低く，糸状体の穿孔性には硬度も条件になることが考えられたので，基物の硬度についても考慮をはらった。貝殻の硬度は，アコヤ貝の真珠層のばあいその生産する真珠から類推して，モース硬度が3.5～4.5と考えられる。この硬度は方解石の硬度が3，霰石は3.5～4であるから，鉱物性の炭酸カルシウムの結晶より高いことになる[25]。

#### 材料および方法

母藻は大阪湾でえられたアサクサノリである。基物としては，その硬度が貝殻のていどか，それよりひくい鉱物をえらんだ。すなわち螢石（Fluorite），方解石（Calcite），霰石（Aragonite），珪灰石（Wollastonite），滑石（Talc），葉蠟石（Pyrophyllite），明礬石（Alunite），重晶石（Barite），斜方沸石（Chabazite）の9種である。これらの鉱物を地学でもちいられる方法にならって，スライドグラス上にレークサイドセメントではりつけ，グラインダーで研磨して透過光線による顕微鏡観察が可能なていどにうすくしたものを用意した。つぎに自浄海水をみたしたバットの底に鉱物面を上にしたスライドグラスをしき，果胞子斑の多い母藻をその上において1日静置し，播種をおこなった。1955年2月13日に播種をおこない4月3日に穿孔状態をしらべた。

## 結果および考察

Table 1. The perforating ability of *Conchocelis*-filaments of *Porphyra tenera* KJELLMAN for inorganic matrices. Culture duration is 50 days form Feb. 13, 1955.

| Matrices | Components | Hardness | Corrosion by acid | Perforating ability for matrices |
|---|---|---|---|---|
| Fluorite | $CaF_2$ | 4 | Corroded by hot sulphuric acid. | All germlings grew into creeping filaments on the surface of matrix. And no perforating growth is observed. |
| Calcite | $CaCO_3$ | 3 | Corroded by cold acid. | Almost all germlings grew into ordinary *Conchocelis*-phase in the matrix. Perforating growth is also the same as in the shell matrix. |
| Aragonite | $CaCO_3$ | 3.5～4 | Ditto. | The same as the above |
| Wollastonite | $CaSiO_3$ | 4.5～5 | Corroded by hydrochloric acid. | Some germlings partially perforated in some spots of matrix. Others creep elsewhere on the surface. |
| Talc | $H_2Mg_4(SiO_3)H_2O$ | 1～1.5 | Unaffected by acid. | No perforating filaments were observed. All germlings creep on the whole surface of matrix. |
| Pyrophyllite | $H_2Al_2Si_4O_{12}$ | 1～1.5 | Partially corroded by hydrochloric acid. | The same as the above. |
| Alunite | $K_2SO_4 3Al_2SO_6 6H_2O$ | 3.4～4 | Corroded by hot potassium hydroxide and hot sulphuric acid. Unaffected by hydrochloric acid. | The same as the above. |
| Barite | $BaSO_4$ | 3 | Unaffected by acid. | The same as the above. |
| Chabazite | $(Ca,Na_2)Al_2Si_2Si_4O_{12}$ | 4～5 | Ditto. | The same as the above. |

第1表にしめしたように，硬度の低い鉱物上に播種された果胞子とみられる生殖細胞のうち方解石，霰石上のものは発芽してあきらかにそのなかに穿孔し，貝殻中とかわらない生長をしめした。とくに透明な方解石中ではきれいな羽状生長をしているのがよく観察できた（第2図参照）。ただ，穿孔しないで表面をはったままの発芽体が，貝殻のばあいより多い傾向がみられた。その他の鉱物中には，珪灰石のある部分にわずかに穿孔しているのが観察されただけで，他のすべてのものには全然穿孔しなかった。すなわち果胞子がガラス上で発芽したときにしめすような糸状の発芽体になって，鉱物面上をはっているだけであった。

珪灰石には全面に穿孔することがなく一部分にしか穿孔していない。珪灰石にはところどころに炭酸カルシウムをふくんだところがあり，酸にあうとこの部分が発泡するから，糸状体は主としてこの部分に穿孔しているものと思われる。

この結果からわかるように基物の硬度は問題ではなく，冷酸にとける物質でなければ糸状体は穿孔しないと思われる。すなわち，糸状体は冷酸でとかすことのできる炭酸カルシウム系の物質にしか穿孔しないと考えられる。したがって炭酸カルシウム系の物質なら，無機物でも生物起原のものでもかわりなく糸状体の基物になりうることがわかった。また貝殻の真珠層は斜方晶系（aragonite）であり，方解石は六方晶系（calcite）であるが，このような結晶系のちがいも問題にはならない。

糸状体は鉱物性炭酸カルシウムにも穿孔生長するから，その生長に対して貝殻中の有機物が不可欠であるとは考えられない。しかし方解石などの鉱物性基物には糸状体の穿入が困難であり，穿入後の生長も貝殻中よりやや劣る傾向がある。この傾向と貝殻中の有機物との関係については今後の検討にまちたい。

## 要　　結

1．糸状体は，貝殻のみでなく，方解石，霰石などの鉱物性炭酸カルシウム系基物にも穿孔しうる。
2．炭酸カルシウム系以外の鉱物性基物には，硬度が貝殻より低くても全然穿孔しないから，硬度は穿孔の条件にはならない。
3．穿孔生長は炭酸カルシウムの結晶系のちがいには関係なくおこなわれる。

## B．糸状体細胞の pH 値と炭酸カルシウムの溶解との関係

糸状体が炭酸カルシウム系の基物中に穿孔して生長するためには，その生長先端が基物を溶解して穿孔しなければならない。そのためには糸状体がなんらかの酸を分泌するか，あるいは糸状体細胞の pH 値が炭酸カルシウムを溶解するに充分なほど低くなければならない。このさい，炭酸カルシウムが実際に糸状体細胞あるいはその分泌液のしめす pH 値のていどで容易に溶解しうるかどうかも問題である。

このような糸状体細胞の pH 値と炭酸カルシウムの溶解性との関係をしらべるために，まず糸状体細胞の pH 値をしらべ，ついで炭酸カルシウムの溶解と pH 値との関係をしらべて考察した。

### 材料および方法

糸状体細胞の pH 値をしらべるために，つぎのような方法をもちいた。

まず，アサクサノリ糸状体が穿孔しているカキ殻の真珠層の部分をてきとうにくだいて，顕微鏡観察ができるていどの薄片にし，つぎにその薄片中の糸状体をいろいろな pH 指示薬で生体染色[1]してその色調をしらべ，その結果から糸状体細胞の pH 値を推測した。

もちいた指示薬はつぎの5種類である。

BPB（ブローム・フエノール・ブルー），MR（メチル・レッド）
BCP（ブローム・クレゾール・パープル），BTB（ブローム・チモール・ブルー）
PR（フエノール・レッド）

この実験は1955年7月におこなった。

炭酸カルシウムの溶解と pH 値との関係をしるためには，つぎのような方法をもちいた。炭酸カルシウムとしては，純粋な方解石を乳鉢でよくすりつぶして粉末としたものを用意し，これを種々の pH 値を有する燐酸カンショウ液中にいれ，そのさい生ずる炭酸ガス（$CO_2$）量をワールブルグ検圧計で測定し炭酸カルシウムの溶解のていどをしらべた。燐酸カンショウ液の pH 値は指示薬法で比色測定した。

この実験は1956年11月におこなった。

## 結果および考察

Table 2. Vital staining of cells of *Conchocelis* of *Porphyra tenera* KJELLMAN with pH indicator pigments. Fragments of filaments-inhabited shell were flaked away from mother matrix in order to stain the cells under microscopic observation.

| pH indicator | pH range and corresponding color range of indicator | Color of stained cells | Estimated pH of stained cells |
|---|---|---|---|
| Brom phenol blue (BPB) | 2.4～4.0 Yellow—Purple | Light purple, partially yellow. | 4.0 |
| Methyl red (MR) | 3.6～6.6 Red—Yellow | Orange. | 4.0～5.0 |
| Brom cresol purple (BCP) | 5.0～6.4 Yellow—Purple | Almost yellow, partially purple. | 5.0～6.0 |
| Brom thymol blue (BTB) | 5.2～7.6 Yellow—Blue | Yellow or light green. | 5.2～6.0 |
| Phenol red (PR) | 6.0～8.0 Yellow—Red | Yellow. | 6.0 |

各種指示薬の0.01％溶液で糸状体を生体染色した結果を総合すると第2表にみられるように糸状体細胞の内容がしめすpH値はほぼ5～6であるとみてよい。

一般に植物原形質のpH値は弱酸性であるといわれている。たとえば *Chara crinita* のそれは5.4～5.6 (5.5) である[60]。また植物細胞液のpH値もいろいろであるが，3.4～6.2 (多くは5.0～6.2) で酸性のことが多い[60]から，糸状体原形質および細胞液のpH値はとくに高くも低くもないといえよう。問題はこのていどのpH値で炭酸カルシウムが溶解するかどうかである。このことをしらべるためにおこなった実験結果および考察はつぎのようである。

pH 5から8まで4段階の1/15モル燐酸カンショウ液それぞれ1.5 ml中に粉末にした方解石を100 mgい

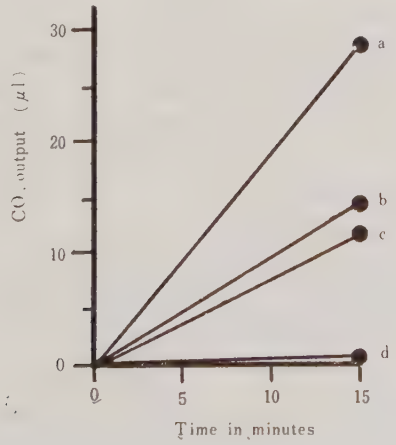


Fig. 12. Solubility of calcite in phosphate buffer solutions which have different concentrations of hydrogen ion. Solubility is expressed in terms of the volume of carbon dioxide released at 30°C. Calcite powder 100 mg, buffer solution 1.5 ml employed. a : pH 5, b : pH 6, c : pH 7, d : pH 8.

れて，30°C で検圧した結果は第12図にしめすように，15分間に pH 7でもかなりの $CO_2$ の発生があり，pH 6， pH 5 ではもちろんそれ以上に発生している。 pH 8 では事実上発生はないとみてよい。 pH 7 でこのようにかなりの $CO_2$ 発生がみられるのは，この液がじっさいにはげんみつに中性でなく，多少酸性であったものと思われる。すなわち， pH 値が中性から少し低いだけで相当量の炭酸カルシウムの溶解があることがこの実験であきらかになった。

このことをふたたびたしかめるために，1/15モル燐酸カンショウ液 1 ml 中に粉末にした方解石 50 mg をいれて 5 分ごとに測定し，第13図にみられるような結果をえた。すなわち多少の相違はあるが，その傾向にお

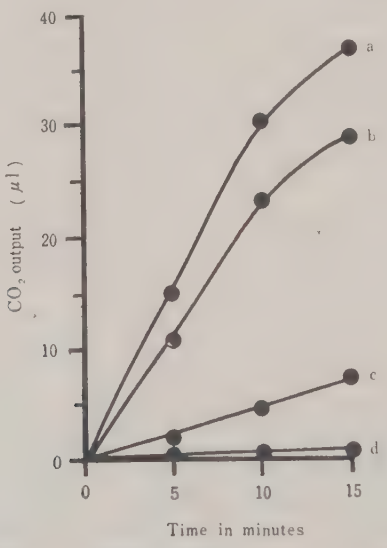


Fig. 13. Solubility of calcite in phosphate buffer solutions. Calcite powder 50 mg, buffer solution 1.0 ml employed at 30°C. a : pH 5, b : pH 6, c : pH 7, d : pH 8.

いてはかわりがない。すなわち pH 7 でもかなりの $CO_2$ 発生があり，pH 6, pH 5 ではさらにいちじるしい。

以上の実験から炭酸カルシウムを溶解するには，極端に低い pH値を必要としないことがわかる。ほとんど中性に近くても酸性側ならばしだいに溶解するものと思われる。したがって炭酸カルシウムを基物として穿孔するばあい， 糸状体の pH 値は極端に低くなくても酸性であれば充分であると考えられる。 事実上述のように糸状体細胞の pH 値はほぼ 5 ないし 6 であるから 糸状体の生長先端の細胞， あるいはそれから分泌される物質の pH 値も 5～6 とみてよい。 したがって糸状体はその 接触面で基物である炭酸カルシウムを溶解することは容易であると考えられる。

陸上植物についてこのような現象をさがしてみると，つぎのようなことがしられている。すなわち，トウモロコシあるいは大豆の種子が，大理石上に盛られた砂中で発芽し生長すると，その大理石の面上に根の生長にともなって侵蝕した根跡がみられるという。これは根が排出した炭酸によって侵蝕がおこったものとされている[20] から，糸状体の穿孔のばあいも同様の機作が考えられる。

## 要　　結

1. 糸状体細胞内容物の pH値は酸性であり，その値はほぼ 5～6 と考えられる。
2. 炭酸カルシウムは pH 7 以下の燐酸カンショウ液で容易に溶けて $CO_2$ を発生する。
3. したがって炭酸カルシウムを溶解するには極端に低い pH 値を必要としない。
4. 以上の事実から，糸状体は貝殻などの炭酸カルシウムを溶解して穿孔する能力を当然もっていてもよいと考えられる。

## 第2節 裸出糸状体の生長

アサクサノリなどのいわゆる果胞子がスライドグラス上で発芽したばあいには，分岐の少ない糸状の発芽体になる。貝殻上に播種された果胞子は，発芽穿孔していわゆる *Conchocelis*-phase になるということがDREW (1949) によってみいだされるまえは，このようなガラス上の発芽はすべて異常発芽[34]と考えられていた。

このガラス上の発芽体は，貝殻中の糸状体にくらべて同じ糸状体でも形態が相当ことなるうえに，貝殻中では旺盛に生長し越夏して生存するのにくらべて，ガラス上では生長がわるく，多くはまもなく死滅する。

このように裸出して発芽したばあいと，貝殻のような炭酸カルシウム系の基物中に発芽穿孔したばあいと，生長のていどや形態がことなることの原因をしらべるために，つぎのような実験をおこなった。

### A. カルシウム塩の影響

果胞子からの発芽体が貝殻などの中に穿孔して生長するためには，その生長先端が基物を溶解しなければならない。炭酸カルシウムが溶解するのは，炭酸ガスとある種のカルシウム塩の形になって分解するからであるが，これらが穿孔した糸状体になんらかの好影響をあたえるから糸状体の生長がよく，逆にガラス上で発芽した裸出の糸状体は，このようなことがないので生長がわるいのではないかと一応考えられる。

したがって，裸出した糸状体にこの両要素をべつべつにあたえてその影響をみれば，あるていどの推測がつくと思われたので，はじめにカルシウムの影響をみる実験をおこなった。

実験は1955年3～4月におこなった。

#### 材料および方法

3月24日に大阪湾で採集したアサクサノリを母藻にして，その果胞子と思われるものを多くのスライドグラス上に播種して培養し，発芽体が多く附着したスライドグラスを，カルシウム欠除の人工海水および塩化カルシウム ($CaCl_2$) を0.01，0.5，0.1モルの各濃度になるように海水中に添加した溶液中にいれて3月26日に実験をはじめた。対照は自浄海水である。カルシウム欠除の人工海水は Van't Hoff 液を基準にした NaCl 2.7 %，KCl 0.07 %，$MgCl_2$ 0.34 %，$MgSO_4$ 0.21 %の組成[21]のものを用意した。調製した培養液の pH 値はすべて対照の自浄海水のそれとかわりがなく 8.2 であった。つぎに上記培養液のそれぞれに2 %の寒天をとかしてシャーレ中にかためた固形培養基をつくり，その上に自浄海水をみたし（人工海水寒天のばあいのみ，その上に人工海水をみたした），それらの寒天面の上に常法どおり播種して，寒天中のカルシウム塩が生長におよぼす影響をみた。播種は3月24日におこなった。

この全実験において，もちいた培養液はすべて等張に近くなるように，0.1モル $CaCl_2$ 海水溶液の滲透圧を基準にしてそれぞれ計算量の食塩 (NaCl) をくわえて調製された。

#### 結　　果

**ガラス上の生長**：ガラス上の裸出糸状体の長さを数個体について測定し，生長のていどを第3表にあらわした。3月29日の観察では対照がいちばん伸長がよく，あとはややおとるが，0.05 および 0.1 モル $CaCl_2$ 海水溶液中では，糸状体細胞の幅がやや広い傾向がみられる。カルシウム欠除の人工海水中では胞子が膨潤して大きくなったものが多く，発芽は全然みられない。

4月2日の観察では，長さにおいて対照と 0.01 および 0.1 モル $CaCl_2$ 海水溶液中のものとは大差がなく，0.05モル $CaCl_2$ 海水溶液中のものはややおとる。しかし $CaCl_2$ 海水溶液中のものはすべて糸状体の幅がややひろく，また分岐もやや多い傾向がみられる。人工海水中では胞子がほとんど死滅した。

4月8日には，長さにおいて 0.1 モル $CaCl_2$ 海水中のものがもっともすぐれ，対照がこれにつぎ，さらに 0.01 モルおよび 0.05 モル $CaCl_2$ 海水溶液中のものの順となる。人工海水中ではすべて死滅した。

Table 3. Effect of calcium salt added to sea water on the growth of *Conchocelis*-filaments of *Porphyra tenera* KJELLMAN germinated on the microscopic slides.

| $CaCl_2$ added to sea water (mol) / Culture duration in days | Control (Natural sea water) | Calcium free artificial sea water | 0.01 M | 0.05 M | 0.1 M |
|---|---|---|---|---|---|
| 5 | Almost all spores germinated. 60～120 μ | Almost all spores swelled. No germination. | All germinated. 70～90 μ | Almost all germinated. Cells slightly thicker. 70～100 μ | Almost all germinated. Slightly thicker. 60～80 μ |
| 9 | Several died. 130～150 μ | Almost all spores died. A few germinated. | Cells slightly broad. Ramification rather frequent. 130～150 μ | Slightly thicker. Ramification rather frequent. 105～135 μ | Cells thicker. 150 μ |
| 15 | 270 μ | All died. | 225 μ | 225 μ | 300 μ |

この結果からみると，0.1モル $CaCl_2$ 海水溶液中ではわずかに対照より伸長がよいようにおもわれるが，だいたいの傾向として海水中に添加した $CaCl_2$ は裸出糸状体の伸長にたいしてあまり大きい影響をあたえないといえよう。

しかし，糸状体の幅や分岐についてはやや好影響をしめすらしく，対照とくらべてずかであるが幅がひろく，分岐も多くなる傾向がみられる。カルシウムを欠除した人工海水中では，胞子はほとんど発芽せずただちに死滅する傾向がみられる。

Table 4. The growth of the *Conchocelis*-filaments of *Porphyra tenera* KJELLMAN creeping on or penetrating in the agar media which were prepared from different sea water described in Table 3 and were filled with natural sea water over them (with artificial sea water only in the case of Ca-free agar medium).

| $CaCl_2$ contained in agar media (mol) / Culture duration in days | Control (Natural sea water) | Calcium-free artificial sea water | 0.01 M | 0.05 M | 0.1 M |
|---|---|---|---|---|---|
| 5 | Almost all spores germinated | Almost all spores floating. No germination. | Majority of spores germinated. | A few germinated | A few germinated. |
| 9 | Rarely ramificated 120～165 μ | No germination. | 150～225 μ | 135～150 μ | 75～105 μ |
| 15 | Almost penetrated. Some creep on the surface of medium. 225～270μ | All died. | Almost penetrated. 375～405 μ | Poor development. 225～240 μ | Poor development. 150～165 μ |

**寒天上の生長**：寒天培養基上で発芽した糸状体には，寒天面上をはうものと，寒天中になるために穿孔するものとがあったが，どちらもガラス上で発芽した裸出糸状体と同じような形態をしめした。

このような寒天中の発芽体の伸長をしらべて生長のていどをみた結果を第4表にしめした。

3月29日，4月2日および4月8日の観察結果を綜合するとつぎのようである。

カルシウム欠除の人工海水でつくった寒天上では，胞子がいつまでも附着しないで寒天面上をころがり，発芽がみられない。

長さにおいて0.01モル $CaCl_2$ 海水寒天のばあいがもっともよく，対照および0.05モル $CaCl_2$ 海水寒天のばあいがこれにつづき，0.1モル $CaCl_2$ 海水寒天のばあいもっともわるい。

分岐と幅については，ガラス上の生長のばあいと傾向においてほとんどかわりがなかった。

## 考　　察

カルシウムが裸出糸状体の伸長に影響をおよぼす濃度は，両方の実験でくいちがいがあってはっきりしないが，ガラス上では0.1モル $CaCl_2$ 海水中でやや生長がよく，対照がこれにつぎ，寒天上では0.01モル $CaCl_2$ 海水寒天上が対照よりややよい傾向をしめすから，ある濃度では多少好影響をあたえるらしい。またカルシウムの存在によって裸出糸状体の幅がわずかに大きく，また分岐もやや多くなる傾向がみられる。一般にカルシウムは原形質膜の維持や細胞膜の形成に必要であるといわれているから，このことはうなずけるが，海水中に通常存在する量以上の量のカルシウムの存在が裸出した糸状体の生長にとくに効果があるようにはみえない。しかしカルシウム欠除の人工海水中では生育しないから，よったくカルシウムを欠いては生存できないことはあきらかである。

## 要　　結

1．ガラス上で発芽した糸状体の生長は，0.1モル $CaCl_2$ 海水溶液中では対照よりわずかによく，寒天培養基上では0.01モル $CaCl_2$ 海水寒天のばあいにやや伸長がよい。

2．$CaCl_2$ 海水溶液中では糸状体の幅がわずかにひろく，分岐もやや多い傾向がみられる。

3．カルシウム欠除の人工海水中およびそれでつくった寒天培養基上では，糸状体は生長しない。

4．裸出糸状体の生存にはあるていどのカルシウムが必要であるが，その生長におよぼす好適条件はあきらかでない。しかし天然海水に含まれる濃度よりわずかに高いらしい。

## B．重炭酸塩の影響

炭酸カルシウムの構成要素のひとつである炭酸の影響を，カルシウムのばあいとほぼ同様にして実験した。実験は1956年1～2月におこなった。

### 材料および方法

ガラス上で発芽した糸状体に対する影響をみるために，0.01％，0.05％，0.1％ の各割合になるように $NaHCO_3$ を自浄海水中に添加したものを用意した。

寒天上の生長をみる方法は，供試塩類がことなる以外はカルシウムのばあいと同じである。すなわち重炭酸ソーダ（$NaHCO_3$）2％および0.5％，炭酸ソーダ（$Na_2CO_3$）0.5％，塩化カルシウム（$CaCl_2$）0.5％の割合にそれぞれくわえた海水溶液をつくり，それぞれの溶液で2％海水寒天培養基をつくって前実験と同様に準備した。

各塩類の海水溶液がしめす調製直後のpH値は，0.5％ $Na_2CO_3$ のばあい9.8に上昇した以外はほぼ自浄海水の8.2とひとしくほとんど変化がなかったが，数日放置すると2％ $NaHCO_3$ では8.4に，0.5％ $NaHCO_3$ では8.3にと少し上昇し，かつ器壁にわずかな白色の析出物を生じた。0.5％ $Na_2CO_3$ のばあいは調製後ただちに白沈を生じた。重炭酸ソーダ添加の海水溶液中の全炭酸量は，実測によると対照の自浄海水よりはるかに多く，また光合成の炭酸源として有効であるといわれている $CO_2$，$HCO_3^-$ 量も海水溶液のpH値から算定すると対照より充分多い結果がえられた。しかし0.5％炭酸ソーダのばあい，全炭酸量および

$HCO_3^-$ 量ははるかに多いが $CO_2$ 量はゼロであった*。

## 結 果

**ガラス上の生長**：1月31日に播種して3月2日に観察した結果は，発芽体の数が少なくて，数量的にあらわすことができなかったが，0.01%，0.05%，0.1% $NaHCO_3$ 海水溶液中では，いずれも対照より生育が良好であった。そして発芽体の形態は根本的には対照とかわりがないが，$NaHCO_3$ 海水溶液中で培養されたばあいの方が細胞の幅がひろく，かつ色素体の色があきらかに濃いものが多かった。

**寒天上の生長**：2月28日に播種したものを3月20日10個体についてその長さを測定し，平均して生長のていどをあらわすと，第5表のようになる。同様に4月3日に5個体について測定し平均した結果を表示した。

Table 5. The growth of *Conchocelis*-filaments of *Porphyra tenera* KJELLMAN creeping on or penetrating in the agar media which were prepared from sea water containing bicarbonate, carbonate and calcium chloride.

| Salts | | Control (Natural sea water) | 2% sodium bicarbonate | 0.5% sodium bicarbonate | 0.5% sodium carbonate | 0.5% calcium chloride |
|---|---|---|---|---|---|---|
| Culture duration in days | 20 | 225 μ | 330 μ | 260 μ | 225 μ | 225 μ |
| | 34 | 350 μ | 525 μ | 555 μ | 500 μ | 405 μ |
| Color of chromatophore | | Rather faint. | Deep. | Rather deep. | Rather faint. | Rather faint. |
| Cell diameter | | Rather slender. | Slightly broad. | Slightly braod. | Slender. | Slender. |

これからみると，あきらかに 0.5% あるいは 2% $NaHCO_3$ をふくむばあいに生長がよく，ついで0.5% $Na_2CO_3$，0.5% $CaCl_2$，対照の順となっている。

糸状体の伸長のみでなく，その太さや色素体の色調についても，$NaHCO_3$ をふくむ寒天上のものは幅がひろくて色が濃く，他のものは細くて色がうすい傾向がみられた。

## 要 結

1. $NaHCO_3$ を含んだ海水中では，含まないばあいより裸出糸状体の生長がよい。
2. 重炭酸塩，炭酸塩，カルシウム塩をそれぞれ含んだ寒天上の裸出糸状体の伸長は，この順序に良好であった。
3. 重炭酸塩を含む寒天培地では，糸状体が太くかつその色素体の色もこくなる傾向がある。
4. したがって，糸状体の穿孔基物となる炭酸カルシウムの構成要素のうち，炭酸が糸状体の生長に有効であると思われる。
5. 貝殻中で糸状体の生長がよい理由の一部は，炭酸の影響と考えられる。

## 第3節 糸状体の代謝

糸状体のガス代謝およびその他の物質代謝については，いままでほとんど研究がおこなわれていない。これは糸状体が貝殻などに穿孔しているために，その生体量および乾燥量などの基準となる量が計量できないこと，また貝殻中に密に繁殖しているとしても糸状体だけの量としてはわずかであって，その代謝による物質量

* これら全炭酸量の測定および各種炭酸物質濃度の算定は，水産講習所・武田薫氏におねがいした。

の変化もごく少なく，測定に困難と誤差がともなうことのためと考えられる。しかしたとえ誤差が多いにしても，代謝に関してなんらかの知見がえられれば，こんごの研究に参考になりうるものと考えて二，三の実験をおこなった。

## A．糸状体による海水中の溶存酸素量の変化

糸状体を培養している海水中の溶存酸素量の変化を，ウインクラー法で測定しその酸素（$O_2$）代謝をしらべた。実験は1956年5～6月におこなった。

### 材料および方法

もちいた糸状体は熊本県水試鏡分場から送付をうけたもので，カキ殻を基物としたアサクサノリの糸状体である。

貝殻面全体に均一に糸状体斑がひろがっているカキ殻を適当にくだいて小片となし，真珠層と殻皮のあいだにある白色の稜柱層，および殻皮をのぞき，糸状体が穿孔している真珠層の部分だけの薄片をつくった。この薄片を数個，海水をみたした酸素定量瓶中にしずかにしずめ，糸状体斑の存在する面を上にむけて全面に光があたるようにして密栓し，一定温度に静置した。一定時間後に酸素瓶中の海水をサイフォンで静かにとりだして固定し，溶存酸素量を測定した。光の照射の必要なときは定温器の外からガラス扉をへだてて照射した。光の照度は，光源からの距離やものかげからの照射などの手段をもちいて加減した。

ふつう実験のはじめには材料を秤量しなければならないが，まえにのべたように糸状体は貝殻中に穿孔しているので，一定量計量して実験にうつすことができない。したがって酸素瓶中で培養する糸状体は大体のめやすとして，糸状体の穿孔した貝殻片の容量2 ml またときには1 ml を基準とした。この値は，海水をみたした酸素瓶へ貝殻片をいれ，排除された水量からもとめた。しかし，このような貝殻の容量のみを基準としては，糸状体の量が正確にあらわせないので，えられた結果を一定の基準で比較するために，実験にもちいた2 ml ないし1 ml の貝殻に存在する糸状体から，そのクロロフイルを主とする油溶性色素を20 ml のエタノールとともに磨砕抽出し，420 mμ における抽出液の吸光極大をベツクマンの光電分光光度計で測定し，えられた $\log I_0/I$ の値を基準にして溶存酸素量の変化量をもとめ，糸状体の酸素の代謝量とした。

この実験においては 420 mμ における $\log I_0/I=0.500$ を基準とした。

上のようにしてえられた油溶性色素の吸光曲線には2つのピークすなわち 420 mμ および 660 mμ があるが前者の吸光度は後者のそれより大きいので，とくに 420 mμ における吸光度を基準にもちいたのである。

### 結果および考察

**溶存酸素量の時間的変化**：暗黒下のばあいと 500 lux の光の照射下のばあいとについて，それぞれ糸状体の酸素吸収および放出を 28°C で時間的に追究した結果はつぎのようである。なお，ここにしめす酸素量は自浄海水中にはじめから溶存していた酸素量をさしひいた値である。

**a．自浄海水中における実験**：光を照射したばあいにえられた結果を図示したものが第14図 a である。最初の数時間はほとんど変化がないが，20，48 時間後にはかなりの溶存酸素量の増加がみられる。これはあきらかに光合成によるみかけの酸素放出の増加によるとみられる。暗黒下でえられた結果を第14図 b にしめした。1時間後には溶存酸素量が増加し，それからしだいに減少している。

暗黒下では呼吸による酸素吸収がおこなわれるので，はじめから溶存酸素が減少しなければならないはずであるから，この一時的増加は海水を酸素瓶からうつして滴定するまでのあいだに空気中から溶入した酸素による実験誤差とおもわれる。もしこの考が正しければ実験はすべて一定の条件下でおこなわれたのでこの値もほぼ一定と考えられる。したがって，すべて1時間目の結果を基準とすれば，この値が消去されて，糸状体の代謝だけにもとづく変化量があらわされるものと考えられる。第14図 b の結果を1時間測定値を基準にして計算すると 0 ml/l（1時間），0.89 ml/l（2時間），−0.81 ml/l（3時間），−1.39 ml/l（20時間），−1.62 ml/l（48時間）という値になり，ほぼ時間ごとに減少していく傾向がみられる。

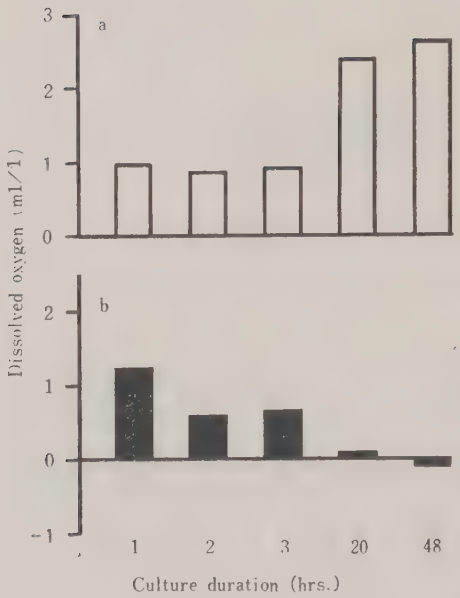


Fig. 14. Changes in dissolved oxygen during the cultivation of *Conchocelis* in sea water at 28°C. Based on a unit quantity of *Conchocelis* material in terms of extractable chlorophyll equivalent to 0.5 of optical density at 420 mμ. Natural sea water was employed. a : illuminated (500 lux), b : in the dark.

Materials employed in the experiments of Fig. 14—19 are *Conchocelis* of *Porphyra tenera* KJELLMAN.

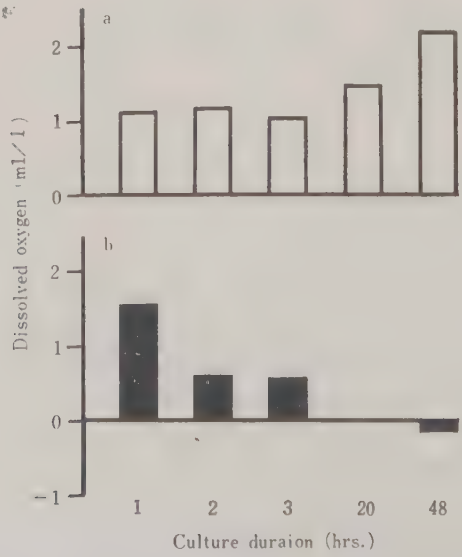


Fig. 15. Successive change of dissolved oxygen during the cultivation of *Conchocelis* in sea water at 28°C. See Fig. 14 for base quantity of *Conchocelis* material. a : illuminated (500 lux), b : in the dark. Boiled sea water was employed.

b. **煮沸海水中における実験**：海水中にすでに溶存しているガスをできるだけ除去するために，いちど煮沸したうえ密閉器中にいれて排気した自浄海水をもちい，前記と同様の実験をおこなった。この操作によって海水中に溶存する酸素は 1/2〜1/3 に減少した。

光照射のばあいは第15図 a にしめすように，第14図 a のばあいとおなじく，溶存酸素が時間の経過とともに増加する傾向がみられる。暗黒下における結果は第15図 b にみられるように，1 時間後の値は増加し，以後はしだいに減少していく傾向をしめす。この結果をまえにのべたことと同じ理由で，1 時間値を基準にして計算すると，0 ml/l（1 時間），−0.76 ml/l（2 時間），−1.11 ml/l（3 時間），−1.71 ml/l（48 時間）という結果になる。すなわち，やはりしだいに減少する傾向になり，呼吸による溶存酸素の減少をしめしているものとおもわれる。

**照度の影響**：照度の差によって糸状体がしめす酸素の代謝量の変化をしらべるために，4 段階のことなる照度下で室温（25〜28°C）実験をおこない，2 日後にえられた結果を比較した。照度計を瓶の位置において，フォト・セルの面の角度をかえて照度をはかり，最大と最小の値をもってその場所の照度とした。

自浄海水中のばあいは第16図 a にしめすように 1000〜2000 lux でかなりの酸素放出がみられるが，50〜

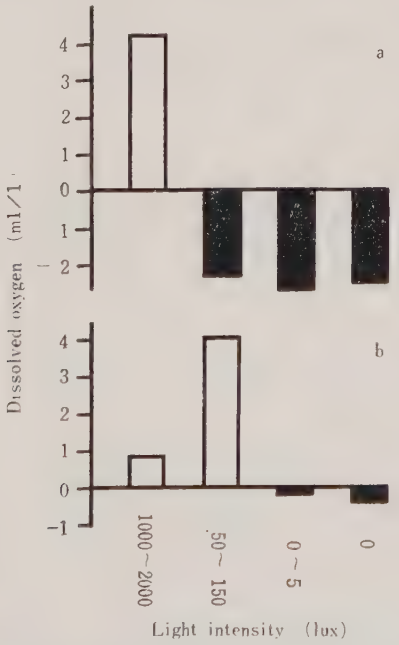


Fig. 16. Effect of light intensity on the change of dissolved oxygen during the 2 days cultivation of *Conchocelis* (room temp.). See Fig. 14 for base quantity of *Conchocelis*.
a : in natural sea water, b : in boiled sea water.

150 lux 以下ではすべて酸素の吸収のみがみられる。このことから 50〜150 lux の明るさでは光合成はおこなわれないようにおもわれる。しかし，いちど煮沸した海水中のばあいは第16図 b にみられるように，1000〜2000 lux よりかえって 50〜150 lux で多量の酸素の放出がみられる。もちろん 0〜5 lux および 0 lux では酸素の放出はみられず吸収がおこなわれている。

このように 2 つの実験で差がみられたのは，培養海水の差というより，その他による実験誤差が大きくでやすいためと考えられるが，両方の結果から少なくとも糸状体は 5 lux 以下では光合成をおこなえず，50〜150 lux 近辺では，他の条件の差でおこなったりおこなわなかったりするものとみられる。

## 要　　結

1．糸状体に光を照射すれば，海水中の溶存酸素量が増加する。これは糸状体の光合成による酸素放出の結果とみられる。

2．暗黒下では，海水中の溶存酸素量はしだいに減少する。この減少は糸状体の呼吸による酸素吸収の結果とみられる。

3．照度 50〜150 lux のばあいには糸状体の酸素放出がみられるときとみられないときがあるが，0〜5 lux 以下では酸素の吸収がおこる。したがって補償点はほぼ 5〜50 lux の附近にあるとみられる。

## B．糸状体のガス代謝

まえに糸状体の光合成，呼吸などの結果にもとづく溶存酸素量の変化をしらべたが，じっさいに糸状体がしめすガス圧の変化をとらえてその光合成，呼吸のていどをみるために，ワールブルグ検圧計[22]をもちいて実験をおこなった。このさい，じっさいにマノメーターにあらわれるガス圧の変化はきわめてわずかであり，このことは貝殻中に穿孔している糸状体の量が生体量にすればいかにわずかであるかということをしめしている。また溶存酸素量の項でのべたような理由で，このばあいもいろいろな誤差をまねく実験上の操作のむずかしさがあり，えられた結果はかならずしも正確とはいいがたい。したがって，ここでえられた結果から，結論めいたことがらをひきだすことはむずかしいにしても，糸状体のしめすガス代謝のていどを知ることは，この方面の知見のまったくみられない現状では必要なことであると考えられる。

実験は1956年11〜12月におこなった。

### 材料および方法

前項の材料を前項と同様にして，その真珠層の部分をできるだけ大きさの薄片にし検圧計の容器中に海水 3 ml とともにいれて実験をおこなった。貝殻は容積にして 0.2 ml である。なおもちいた貝殻をくだいて，10 ml エタノールでクロロフィルを抽出し，その 420 mμ における吸光度を 0.3 にそろえて計算し，糸状体量を同一レベルにしたものとして比較した。

暗黒下で呼吸による酸素の吸収をみるばあい，副室に 0.5 ml の10%苛性カリ（KOH）溶液をいれたものと，いれないものと 2 本ならべて測定をおこなった。

実験温度は 25°C または 30°C である。

### 結　　果

**暗黒下の場合**：えられた結果を図示したものが第17図である。多くの実験をおこなってほぼ同様の曲線をえたが，そのうち数例をしめした。これでみると多少の不整一があるにしても，だいたい酸素の吸収量と時間との関係は直線的とみてよい。そして $CO_2/O_2$ を計算すると第17図中の説明のように，だいたい 0.5〜0.7 になる。

**光照射の場合**：電燈または螢光燈の光を恒温水槽中の水面上から照射して実験した結果は第18図にみられるように条件によってことなるが，いずれも光合成にもとづくとみられるガスの時間的増加がみとめられる。これはもちろんみかけ上の量であって，常法[2]にしたがえば一定時間の光照射後，暗黒下での実験にうつしてひきつづき測定しなければならないが，この実験のていどでは，照明や測定時間，温度等の関係から長時間の測定は不適当であり，とくにこのような実験をおこなわなかった。

1959年に補足しておこなった実験の結果を第19図にしめす。

このときの糸状体量は吸光度を一定に統一していない。恒温槽の水面上から電燈光を照射し，容器のある位置での照度が約 1,000 lux になるようにしたが，糸状体は容器中にあり，また容器中の糸状体は振盪中にうらがえったりかさなったりして全面に光をうけることができなかった。したがって，じっさいに当った光は 1,000 lux に達してなかったと考えられる。

温度は 25°C で 1 時間ごとに明暗をくりかえして実験をおこなった。結果は図にみられるように，光の照

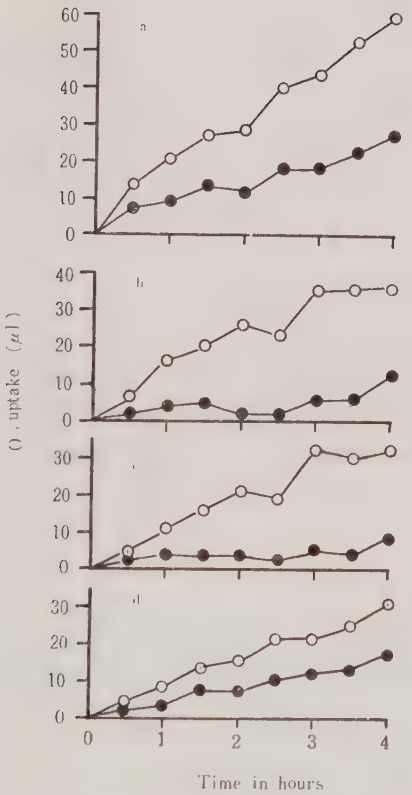


Fig. 17. Manometric measurements of oxygen uptake by *Conchocelis* in the dark. Sea water 3.0 ml, shell volume 0.2 ml in the vessel (solid circles) and 0.5 ml of 10 % KOH placed in the central well (open circles). a, b, c : 30°C, d : 25°C. See Fig. 14 for base quantity of *Conchocelis*, but 0.3 at 420 mμ. Culculated RQ are as follows, a : 0.54, b : 0.65, c : 0.74, d : 0.44.

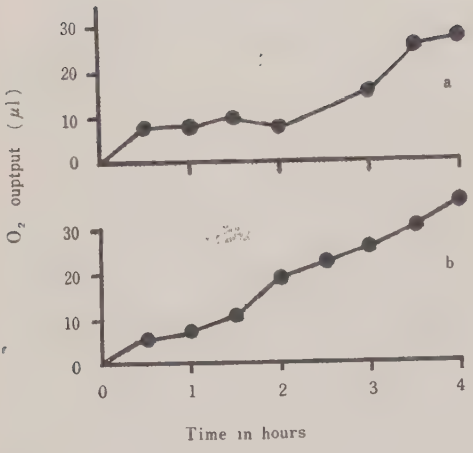


Fig. 18. Manometric measurements of $O_2$ output by *Conchocelis* when illuminated. Sea water 3.0 ml, shell volume 0.2 ml employed. a : 30°C, b : 25°C. Quantity of *Conchocelis* as the case of Fig. 17.

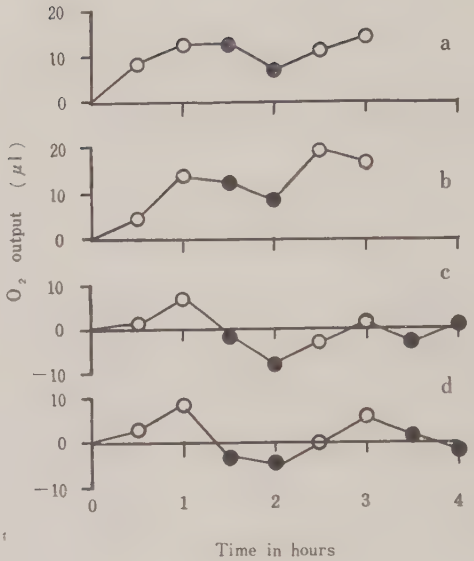


Fig. 19. Manometric measurements of gas exchange by *Conchocelis* under the alternation of light and dark (25° C). Sea water 3.0 ml, shell volume 0.2 ml employed. Open circles : under lighting, closed circles : in the dark. Optical density at 420 mμ in ethanol extracts of materials are as follows, a : 0.450, b : 0.520, c : 0.700, d : 0.570.

射下ではガス量が増加し，暗黒下では減少するが，その値は一定でなく，また変化がごくわずかで誤差も多いと考えられるのでなんらかの結論をひきだすにいたらなかったが，傾向だけはうかがわれる。

## 要　　結

1. 光照射下では，糸状体は光合成の結果とみられる $O_2$ を放出する。
2. 暗黒下では，呼吸の結果とみられる $O_2$ の吸収がみられる。
3. 糸状体の呼吸商は0.5～0.7とみられる。

## 第4節　糸　状　体　の　色　素

糸状体が母藻である葉体とその形態において非常にことなることは，すでによく知られるようになった事実である。その色素体も葉体細胞がもつ星状の色素体とはあきらかにことなった板状の色素体であり，ときにはその形状がはっきりとみとめにくいときもある。このような糸状体の色素体中にも，当然生長に関係の深い光合成色素が含まれていると予想されるが，糸状体の色素体中の色素が，その貝殻穿孔という特異な生態に関連して，母藻の色素と同じものかどうか興味ある問題と思われたので，この点について知るため1955年6～9月に実験をおこなった。すなわちアサクサノリ糸状体をはじめとし，その葉体，ウシケノリの葉体と糸状体などについて，それらの色素を抽出し比較研究をおこなった。

## 材料および方法

もちいた糸状体は前節のものと同じである。葉体は大阪湾に自生しているアサクサノリと同定されたものおよび和歌山産のアサクサノリと同定された乾ノリである。ウシケノリは大阪湾に自生していたものである。その糸状体は果胞子と思われるものを著者がカキ殻上に播種し発芽穿孔させて培養したものである。

以上の材料の色素についてしらべるための方法としては，まず，その生体の吸光曲線をしらべて，含まれている色素全体の吸光曲線をしり，生体における吸光特性をしるてがかりをえ，つぎに生体色素の構成を知るために，有機溶剤，燐酸カンショウ液などの溶媒で抽出して，そのおのおのの抽出色素の吸光曲線をしらべた。特定のものについては，カラムのクロマトグラフ法で分別吸着させ，それからふたたび溶離してえた色素の吸光曲線を測定した。

吸光曲線はすべてベックマン光電分光光度計により測定をおこなったが，試料植物が生きているばあいの測定には，特別な工夫[40]をほどこした。この方法は BIEBL (1953) が *Porphyra umbilicalis* の葉体の透過率曲線について，環境要因の影響をしらべたときにもちいた方法と同じような方法である。すなわち，アサクサノリ葉体を分光光電光度計用の試料セル（1 cm 角，深さ約 5 cm）の一方の内側にセルの面積よりやや小さく切ってはりつけ，つぎにしわがよらないようにうすいスライドの小片でこれをおさえ，セルには海水をみたす。

貝殻に穿孔している糸状体の生体のばあいには，糸状体が密に穿孔して発育している貝殻のうち，真珠層の部分をえらんでなるべくひろい面積の薄片（200～300 $\mu$）を多くつくり，試料セルの光透過部いっぱいになるようにすきまなくならべ，うすい 2 枚のスライドのあいだにはさむ。

ウシケノリ葉体のばあいには，2 枚のうすいスライドのあいだに葉体をすきまなくならべてはさむ。

吸光曲線はすべて可視部（400～800 m$\mu$）における吸光度（$\log I_0/I$）からもとめた。

## 結果および考察

### Ⅰ．アサクサノリ

#### a. 葉体とその抽出色素の吸光曲線

アサクサノリ生葉体の吸光曲線およびその乾物の水抽出液ならびに，アルコール抽出液の吸光曲線を第20図にしめした。生葉体の吸光曲線（A）は今までの多くの研究[12]から知られているように，水抽出液からえられる phycobilin の吸光曲線（B）と，エタノール抽出液からえられたクロロフイル a，カロチン等の吸光曲線（C）の合成されたものであることがわかる。生葉体における曲線の各ピークは分別した色素群溶液の曲線と相対応するピークがほとんど一致する。ただ 420 m$\mu$ 前後におけるピークがAとBで多少ことなるのは，前者は生葉体，後者は乾物からの抽出液であるという材料の状態の差にもとづくためと思われる。

水抽出液のしめす曲線（B）は，phycobilin の吸光曲線であって，r-phycoerythrin (497.5, 540, 566 m$\mu$)[49]，r-phycocyanin (553, 615 m$\mu$)[49] の吸光曲線の合成されたものとおもわれる。このことはそれぞれのおもなピークの位置から充分推定できる。

#### b. 糸状体の吸光曲線

糸状体が穿孔発育している貝殻の薄片の吸光曲線は第21図Aにみられるように生葉体の吸光曲線とピークの数，位置においてかわりはない。形状と対応する各ピークの高さはややことなっているとはいえ，短波長部で高く，長波長部で低い生葉体の吸光曲線とほとんど同じ傾向をしめしている。これは，糸状体が自然の海底等で貝殻とともに存在するばあいの状態をしめすものである。

しかし糸状体の穿孔していない貝殻の真珠層の部を対照にとって測定した吸光曲線は第21図Bにしめしたように，第21図Aとはかなりことなった傾向をしめす。すなわち 400～700 m$\mu$ の間ではほとんど各ピークの高さがかわらない。

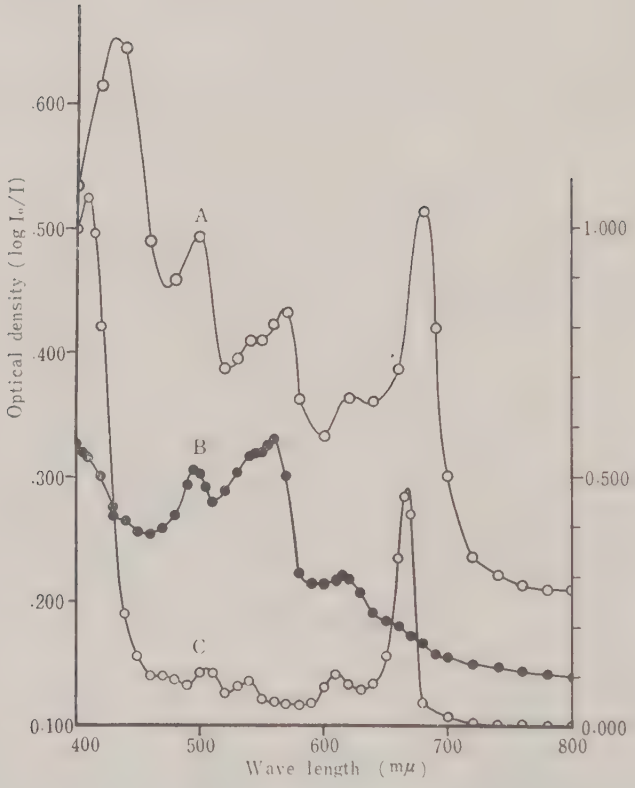


Fig. 20. Spectral absorption curves of *Porphyra tenera* KJELLMAN. A : Fresh intact thallus, B and C : water and ethanol extracts from dried material, respectively. A refers to right scale, B and C to left scale.

カキ殻白体（厚さ 200～300 mμ）の吸光曲線は第21図Cにみられるように，青緑色部に高く赤色部にむかってなだらかに下る曲線であり，第21図Bにしめされた曲線は第21図Aの曲線から第21図Cの曲線の各対応する値が差引かれたものと考えてよく，裸の糸状体のみではこのような吸光曲線をしめすものと思われる。すなわち，貝殻による光吸収の影響のない糸状体自体の色素による光吸収は，アサクサノリ葉体のばあいにくらべて長波長部における吸光が，短波長部における吸光より比較的おとっていると考えられる。

**c. 糸状体の色素**

糸状体の吸光特性が，葉体のばあいと前述のような差はみられても，ピークの数，位置などにかわりがないことは，色素の構成においては葉体と糸状体とかわりがないことをしめしている。それでまず水溶性色素である phycobilin を抽出してしらべた。

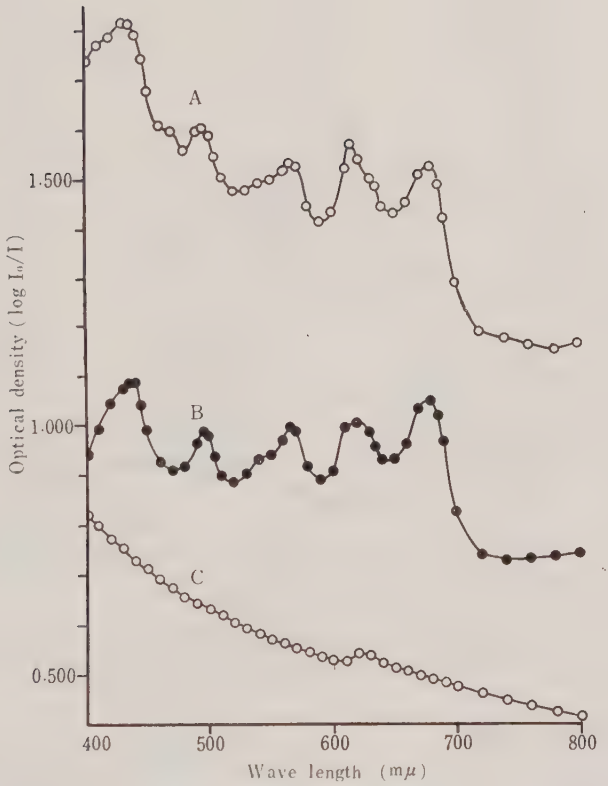


Fig. 21. Spectral absorption curves of shell plates.
A : *Conchocelis*-inhabited shell versus sea water, B : inhabited shell versus non-inhabited shell, C : non-inhabited shell versus sea water.
Materials employed in following experiments (Fig. 21—24) are *Conchocelis* of *Porphyra tenera* KJELLMAN.

抽出は常法のように，蒸溜水に少量の塩（ここでは食塩）をくわえたもの，および 1/10 モル燐酸カンショウ液をもちい，貝殻ぐるみ乳鉢中で擂細しておこなった。抽出したときの pH 値は，前者で約 6.8，後者では約 5.4 であったが，pH 値が低い方がよく抽出されたので，この抽出液を遠心分離（3,000r. p. m. 約 5 分）して残渣をのぞいた phycobilin 溶液を測定してえた吸光曲線は第22図Aのようである。

この曲線から，糸状体の phycobilin と葉体の phycobilin と本質的にかわりなく，やはり phycoerythrin と phycocyanin の混合物であることがわかる。ただ 540 mμ[49] 附近におけるピークはあまりあきらかでない。

糸状体をエタノールで抽出した溶液の吸光曲線は第22図Bのようで，まったく葉体のばあいと同じく主としてクロロフルイ a（432.5，665 mμ …メタノール抽出）[49] と β カロチン（452，482 mμ …エタノール抽出）[49] と思われる吸光曲線をしめす。

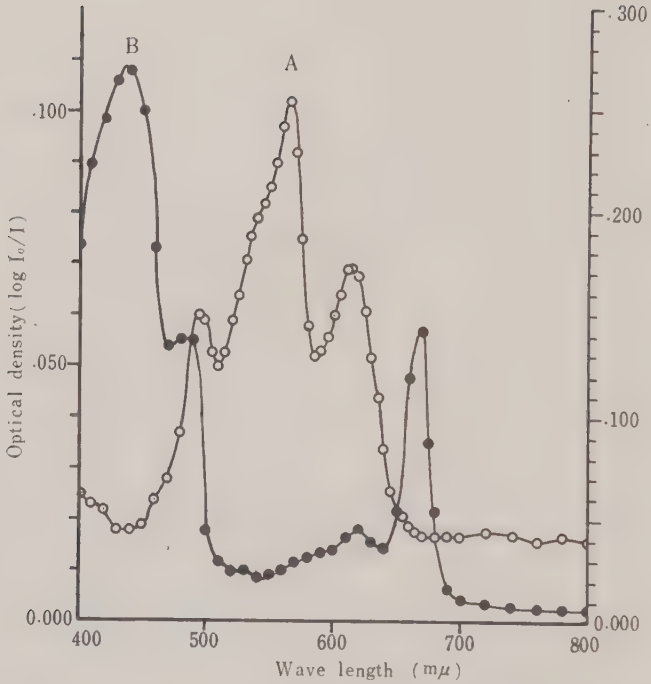


Fig. 22. Spectral absorption curves of water extract (phycobilin) of *Conchocelis* (A), ethanol extract of *Conchocelis* (B). A refer to right scale, B to left scale.

**d. 糸状体の phycobilin の分離**

これまで紅藻の phycobilin は，3ピークをもつ r-phycoerythrin (497.5, 540, 566 mμ)[49] と2ピークをもつ r-phycocyanin (553, 615 mμ)[49] とからなっているといわれている。たとたば *Rhodymenia pacifica* の r-phycoerythrin では 497, 537, 564 mμ のピーク[19] が測定されている。またアサクサノリの r-phycoerythrin についても3ピークをもつといわれていたが，HAXO *et al.* (1955) はアサクサノリの r-phycoerythrin は2ピークをもつだけで2番目のピークを欠いていると報告している。このことは *P. nereocystis* についてもしられている。[18] 著者はこの点を糸状体についてたしかめるために，水抽出液をカラムのクロマトグラフで分別吸着させ溶離してえた液の吸光曲線を測定した。カラムとしては直径約 12 mm，高さ 20 cm のガラス管に，アルミナと3燐酸カルシウムを 5 : 1 の割合に混合したもの[53] をもちいた。またときにアルミナ単独をつめて吸着剤とした。

まず糸状体を pH 6.2 の1/10 モル燐酸カンショウ液で抽出した液をカラムに通して分別吸着させた。実験はできるだけ低温でおこなった。吸着層は第23図のように最上部に緑色の薄層があり，やや下ってうすい青紫色の比較的せまい層があり，一番下に赤色の幅のひろい層ができる。最上層部はいくらかの残渣とクロロフィルなどを含んだものの吸着層と思われるので除外して，青紫色層と赤色層とをそれぞれふたたび1/10 モル燐酸カリウム液 (pH5.4) で溶離し，その吸光曲線を測定した。赤色層からえられた結果を第24図にしめした。この曲線におけるピークの位置（約 495, 545, 565 mμ）は，藤原（1955）が結晶としてえたアサクサノリ葉体の r-phycoerythrin のピークの位置（496, 546, 560 mμ）とだいたい一致する。すなわち，あきらかにこの赤色層は r-phycoerythrin の吸着層である。しかしこの曲線は第2のピークにあたる部分があいまいであり，とくに曲線 B では "shoulder" としてしかあらわれていないから，どちらかというと

Fig. 23. Column chromatogram of phosphate buffer extract from *Conchocelis*. Mixture of five parts of alumina and one part of tricalcium phosphate is employed for adsorbent.
a : light green tinted zone retaining chlorophyll and some debris,
b : purple tinted zone retaining phycocyanin, c : pink tinted zone retaining phycoerythrin.

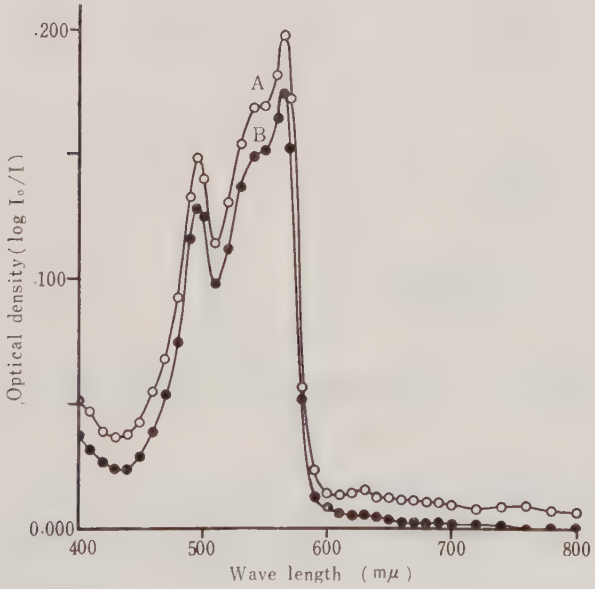


Fig. 24. Spectral absorption curves of phycoerythrin separated by column chromatography from the water extract of *Conchocelis*.
A : middle peak recognizable, B : middle peak obscure.

HAXO *et al*. の2ピークの r-phycoerythrin variant であると考えるのが妥当かもしれない。

青紫色層からは，赤色層とことなり色素が溶離しがたく，燐酸カンショウ液の pH 値，濃度などをいろいろ変化させても，予想された phycocyanin の吸光曲線をしめす抽出液がえられなかった。もともと糸状体中の phycocyanin の含量が，phycoerythrin にくらべて比較的低いと考えられる上に，原材料が少な

いこともその原因と思われる。phycocyanin の存在は第 21，22 図における 615 mμ のピークおよびカラム上の青紫色層の存在からみてたしかであるが，その吸光特性，すなわち *P. perforata* で報告された 2 ピークの r-phycocyanin [19]かどうかたしかめることができなかった。同じく HAXO *et al.* (1955) によって *P. perforata* にみとめられた allophycocyanin (650 mμ) らしいものも，分別測定することができなかったが，これは allophycocyanin が存在してないという意味ではなく，抽出技術の問題と考えられ，さらに検討を要する。

## Ⅱ．ウシケノリ

ウシケノリの生葉体およびその乾物の水抽出液ならびにエタノール抽出液のそれぞれについて吸光曲線を測定し，それらとウシケノリ糸状体の吸光曲線とを比較した。ウシケノリ糸状体の吸光曲線は，アサクサノリ糸状体のばあいと同様にしてえられたが，貝殻に穿孔しているウシケノリ糸状体の生育密度が少なかったために，ピークが多少不明瞭にあらわれた。これらの各吸光曲線は第25図にしめされている。

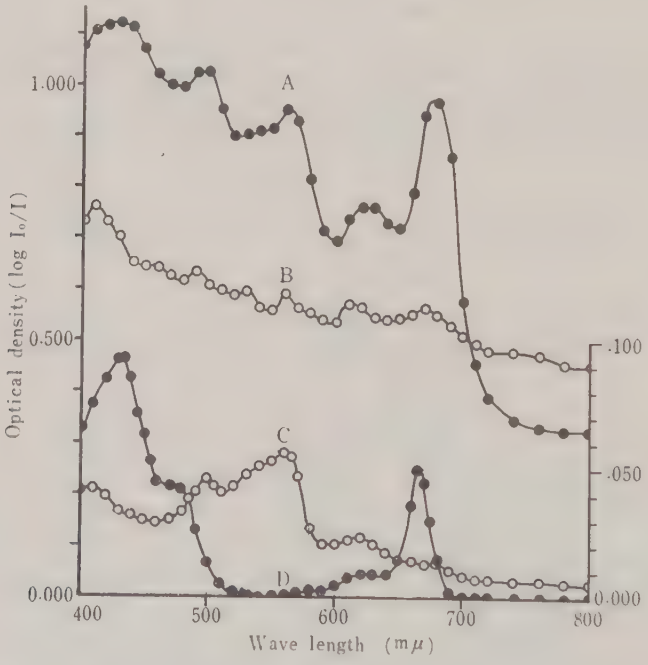


Fig. 25. Spectral absorption curves of *Bangia fusco-purpurea* thalli (A), shell-boring *Conchocelis*-phase of *Bangia* (B), water extract of *Bangia* thalli (C) and ethanol extract of *Bangia* thalli (D). A, B, C refer to right scale, D to left scale.

第25図Aはウシケノリ葉体の吸光曲線であって，第20図Aのアサクサノリ葉体の曲線に相当し，その特性はほとんど同じである。ウシケノリ糸状体の吸光曲線（B）は上述のように生育密度がうすかったために，曲線の起伏があいまいなものになったが，そのピークの位置は，葉体のばあいのピークの位置とほとんどかわることなく，したがってアサクサノリ糸状体のばあいともいちじるしい差はない。第25図CおよびDはそれぞれ水抽出液の吸光曲線およびエタノール抽出液の吸光曲線である。

## 要　　結

1．アサクサノリ糸状体が穿孔している貝殻の吸光特性は，アサクサノリ葉体の吸光特性とほとんどかわ

らない。

2. アサクサノリ糸状体が穿孔していないカキ殻真珠層の吸光曲線は，短波長部で高く，長波長部で低い傾斜をしめす。このことからアサクサノリ糸状体の吸光特性は，葉体よりやや深い生育場所に適応しているようである。
3. 抽出されたアサクサノリ糸状体の水溶性色素，油溶性色素の特性も，葉体のものとほとんどかわらない。
4. アサクサノリ糸状体の水溶性色素を，カラムクロマトグラムで分別吸着させ，ふたたび溶離してえられたものは2ピークを有する r-phycoerythrin variant らしい。
5. ウシケノリ葉体の吸光特性は，その水溶性色素，油溶性色素がしめす吸光特性の合成されたものである。またその糸状体の吸光特性は葉体のそれと同じである。

# 第3章　ノリ糸状体の生長と環境要因との関係

アサクサノリなどの糸状体が自然の海中において生育しているばあいでも，人工的に培養されているばあいでも，その生長が多くの環境要因に影響されていることはいうまでもない。したがって，糸状体の生長におよぼす環境要因の影響をしることは，糸状体の生育条件や培養条件をしるためにきわめて必要なことである。

このような観点から，いままでにもアサクサノリなどの糸状体の生育と環境要因との関係をしらべた研究がかなりおこなわれてきた。黒木・平野（1955b）は，乾燥，海水塩分，光線が糸状体の生育におよぼす影響について，同じく黒木・平野（1956b）は，糸状体の生長と水温との関係をみている。また斉藤（1956b）は，糸状体の生長成熟におよぼす塩分，乾燥などの影響を，竹内他（1956）は糸状体の致死条件について，山崎他（1957）は，糸状体の生長および胞子嚢形成，放出に対する稀釈海水の影響についてそれぞれくわしく検討をおこなっている。最近の研究では，右田（1959）が糸状体の生長におよぼす環境条件と培養液のpH値変化についてかなりくわしく追究している。これらの諸研究の結果から糸状体の生長条件について多くのことがあきらかになったが，なお環境要因として検討されるべきものが二，三のこされていると思われる。たとえば，生長物質の影響，炭酸源の問題など当然しらべなければならないものであろう。

ここではこのような環境要因をふくめた多くの要因が，単に糸状体の貝殻中における水平方向の生長のみならず，垂直方向の生長にもおよぼす影響をしらべて，くわしく検討をおこなった。

この章においては，糸状体の伸長のていどをもってその生長のていどをあらわすことにし，分枝や肥大については特別のばあいのみ言及することにした。

## 第1節　海水濃度・光線・温度の影響

海水の塩分濃度，光の照度および水温などが培養中の糸状体の生長にどのような影響をあたえるものか，その水平，垂直両方向の生長を対象にしてしらべた。

### 材料および方法

糸状体は，下関市吉見地先で増殖されていたアサクサノリを母藻にして，アコヤ貝殻の内面に播種してえられたものである。以下この章の各節における供試糸状体は，すべて上記のものと産地も方法も同様にしてえられたものである。

培養方法および条件は各項にゆずり，ここでは一般的な計測方法について記載する。

まず各条件で培養した貝殻をいままで用いてきた方法どおりに断面のプレパラートを作る。つぎにこれらのプレパラートについて，顕微鏡下で糸状体の垂直方向の枝の長さをミクロメーターで計測する。すなわち，各プレパラートについて任意の視野をえらび，その中で表面に直角に近くかつもつとも長い枝の長さをはかる。このような計測を同一プレパラートについて30回おこなってえた値を平均して測定値とした。実さいにはなるべく測定のかたよりをふせぐために，10回ずつの計測を日時をかえて3回おこなっている。しかし，どの実験においてもこれら3つの平均値のあいだに大きな差はみられず，また変化の傾向もまったくかわりがなかったので，全部を総平均して結果とした。

また各実験について，糸状体の水平方向の生長が観察できるプレパラートを作り，それについても測定をおこなった。このばあい母胞子を中心とした糸状体の長径にあたる主枝の長さを30（あるいは20）個体についてはかって平均した。このような水平垂直両方向の生長に対する計測法は，とくにことわらないかぎり，以下すべて同様である。

## 結　　果

**生長と培養期間との関係**：各要因の影響を知るまえに，ふつうに室内培養（1958年12月６日,同18日播種）したばあいの生長についてしらべた。これらの培養（室内散光，室温，自浄海水中）でえられたプレパラートについて，その垂直方向の生長を上記の方法で測定した（第26図ａ）。

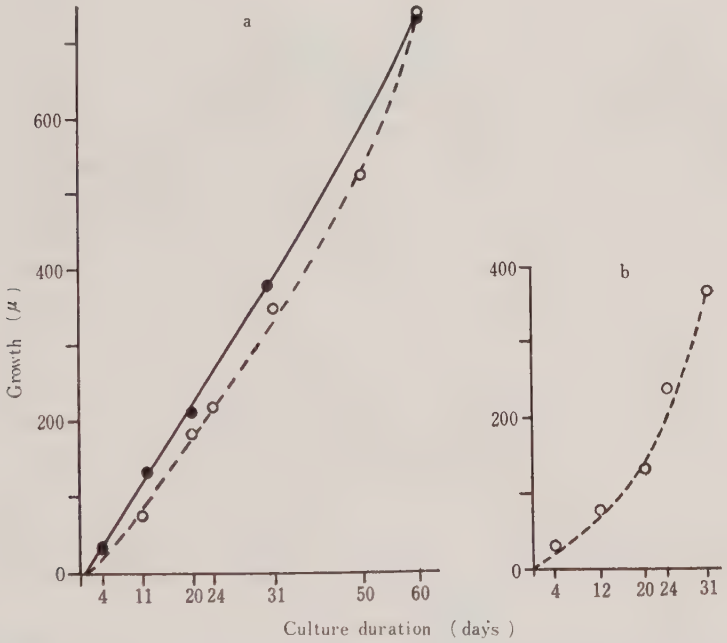


Fig. 26. Relation between the growth in *Conchocelis*-filaments and culture duration (room temp.). Growth is expressed by the length of filaments elongated for vertical (a) or horizontal (b) direction. Open circles : from Dec. 6, '58, solid circles : from Dec. 18, '58.

All materials employed in following experiments (Fig. 26—39) are *Conchocelis* of *Porphyra tenera* KJELLMAN.

これでみると，垂直方向の生長は上記の２つの培養実験において，60日間ではほぼ直線的といえよう。60日以降は，垂直方向の枝は貝殻の外面（下面）に達したのでそれ以上は測定ができなくなった。

この結果からみて，大体一定条件なら糸状体の垂直方向の生長は直線的とみてよい。

この実験について，同時に水平方向の生長を30個体測定した（第26図ｂ）。

このばあい，水平方向に伸長した主枝はその末端が貝殻内層に沈む傾向があり，また30日以上培養したものでは，各個体の主枝がさくそうするので水平方向の測定が困難になった。したがってあまり断定的なことはいえないが，がいして水平方向の生長はその初期において指数曲線的な傾向をしめしているようにみえる。

**海水濃度の影響**：ふつうの海水濃度を１として，だいたい 2, 1, 1/2, 1/8 倍の濃度に濃縮および稀釈した海水で糸状体を培養し，塩分濃度が生長におよぼす影響をみた。稀釈度と塩分濃度，滲透圧との関係を第６表にしめす。培養は温度 20°C，昼光色螢光燈下（照度が培養用の角型小バットの外側で 500 lux になるように，また光は貝殻面に直角にあたるように照明した）でおこなわれた。

Table 6. Chlorosity (g/l, 20°C) and osmotic pressure (atm. 20°C) of different concentrations of sea water employed.

| Concentration | 2.0 | 1.0 | 0.5 | 0.125 |
|---|---|---|---|---|
| Chlorosity | 39.9 | 21.9 | 11.6 | 2.8 |
| Osmotic pressure | 52.1 | 31.0 | 13.3 | 3.9 |

播種は1959年2月19日であるが播種直後の塩分濃度の影響をさけて，23日になってからはじめて各濃度の海水にうつして実験をはじめた。サンプリングは播種してから15日目，30日目の2回である。

塩分濃度がことなる海水中での糸状体の垂直的方向の伸長は，対照（1倍）のばあいがもっともよく，1/2倍で伸長がおち，2倍，1/8倍では極端にわるくなっている（第27図a）。高塩分側の傾向は，測定数が少ない

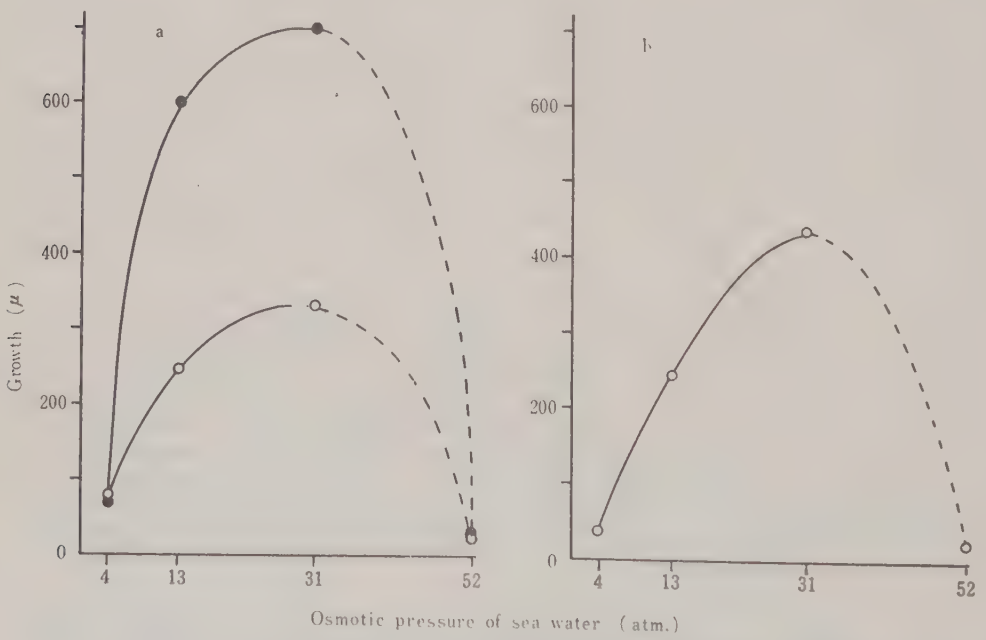


Fig. 27. Effect of sea water concentration on the growth of filaments (20°C. 500 lux). a : growth for vertical direction, b : for horizontal direction. Open circles : 15 days, solid circles : 30 days.

ので破線であらわした。

15日目の結果において2，1/8倍でやや伸長がみられているのは，各濃度にうつすまえの伸長があらわれているものとみられる。15日以後30日までの間には，このような極端な高濃度および低濃度では，伸長はまったくおさえられている。

水平方向の生長も同じ傾向がみられる（第27図b）。

**光線の影響**：水面での照度がそれぞれ5，50，500，2,000 luxになるように，40 W 真天然白色螢光燈の下にそれぞれきょりをおいて培養容器を設備し，培養（室温，自浄海水中）した。播種を2月24日におこな

い，あいだ1日静置して26日から実験にうつし，それから15日目，30日目の2回サンプリングして観測した。

その結果を第28図および第29図にしめした。垂直方向の生長についてみると5 lux 照射の15日後の結果ではわずかな生長がみとめられるが，以後30日目にいたるまでの間には生長がみられない。この生長は播種後1日静置したときのものであり，以後の生長停止は受光不足の結果とみられる。したがって5 lux では生長できないといえよう。5 lux 以上では照度がますにつれて生長が促進されるが，照度と生長度との関係は直線的でなく，この曲線からみて2,000 lux あるいはこれよりやや高い照度で生長の度合が最高に達するものと思われる。この傾向は15日目も30日目もかわりがない。

15日間の水平方向の生長を20個体について測定した結果（第28図b）は，やはり垂直的生長のばあいと傾向においてはかわりがない。30日間培養したものでは測定が困難であった。

**温度の影響**：室温，20°C，25°C の温度について実験した。室温は正午の平均室温であらわせば大体 14〜15°C前後であった。

なお培養ビンを天然白色螢光燈下でガラスでおおっただけのばあいと，ポリエチレンや硫酸紙でおおって照度を落したばあいとについて実験した。

最初の実験を，1959年12月10日に播種したものについて，12日から開始し，10日後，20後の2回サンプリ

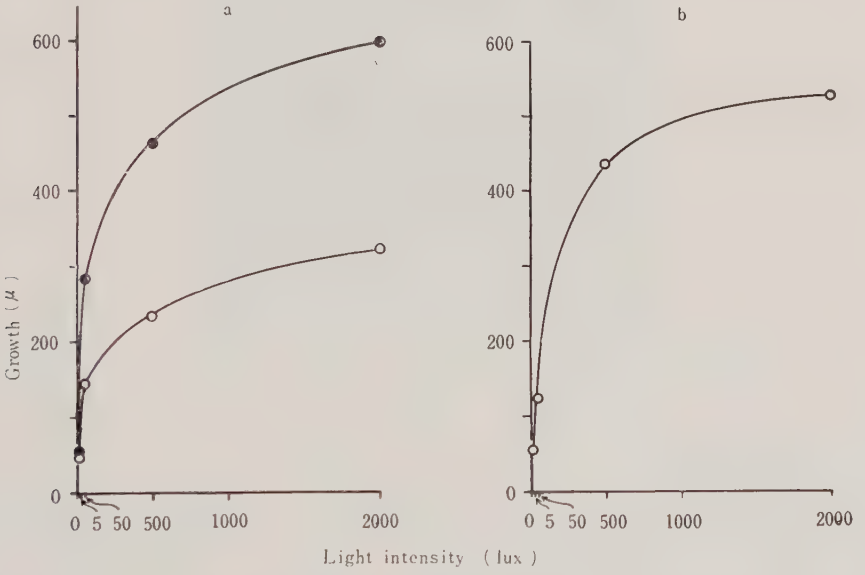


Fig. 28. Effect of light intensity on the growth of filaments at room temp. a : growth for vertical direction, b : for horizontal direction. Open cirlces : cultured for 15 days, solid circles : 30 days.

ングをして糸状体の垂直的生長を測定したが播種の密度が大きかったため水平方向の生長を測定することができなかった。なお，このときの室温は平均15°Cであった。

えられた結果を第30図にしめす。15°Cより20°Cで生長が相当よいが，25°Cでは20°Cよりわずかによいかあるいはほとんどかわらない。この傾向は，10日間の培養（第30図a）でも20日間培養（第30図b）でもかわりがないが，培養がながくなると25°Cでは生長がいくぶんわるくなるようにみられる。温度条件と関連して光の影響をみると，1,000 lux 照射のばあいが（第30図B），500 lux 照射のばあい（第30図A）より20°Cにおいて生長がやや促進されるようにおもわれるが，全体として，1,000 lux と 500 lux とでは生長の

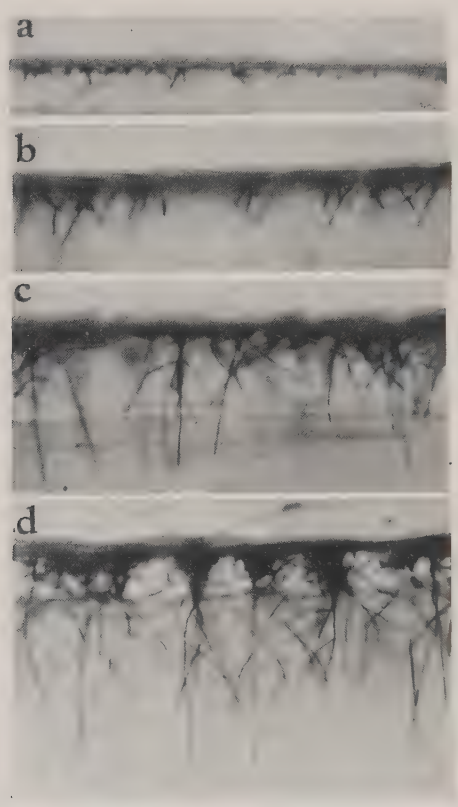


Fig. 29. Vertical growth of *Conchocelis* under the illumination of different intensities. Cultured for 15 days (room temp.). ×100. a : 5 lux, b : 50 lux, c : 500 lux, d : 2,000 lux.

ていに大差がないといえよう。

つぎに，第2回目の実験を12月22日に播種して23日からはじめた。この実験では，光の照度を1,000，500、100 lux の3段階にした。室温は平均14°Cであった。このばあい水平方向の生長を5日後と10日後に，垂直的生長を10日後に測定した。結果を第31図にしめす。

すなわち，垂直的生長（第31図C）ははじめの実験とほぼ同様の傾向をしめしている。水平的生長も垂直的生長と同様の傾向であって、20°Cでは14°Cよりよく、25°Cでは20°Cとほとんどかわらないかあるいはかえって20°Cよりわるい

しかし，光が弱くて 100 lux のような照度であると，温度の影響はほとんどあらわれない。

また以上の結果を光の照度を規準にして図示すると第32図のようになる。

これらの結果からアサクサノリ糸状体の生育適温は 20°C 附近であり，また糸状体の生長におよぼす光の効果は適温とおもわれる 20°C においてあらわれることがわかる。

## 考　　察

糸状体は低塩分に弱いといわれているがこの実験における結果では，1/2倍濃度の海水中の生長は対照にく

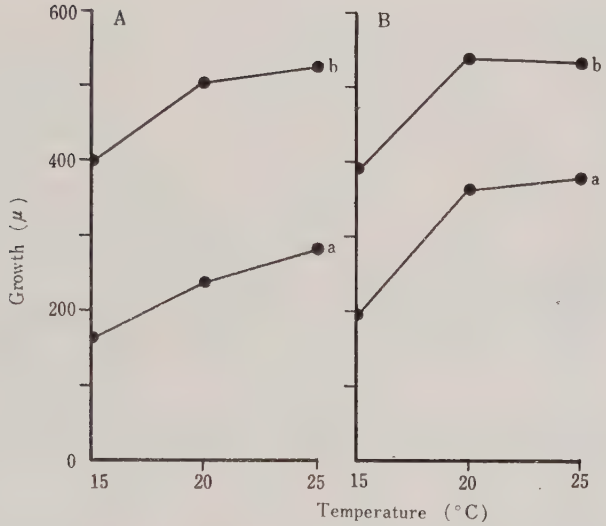


Fig. 30. Effect of temperature on the growth of *Conchocelis*-filaments for vertical direction. A : 500 lux, B : 1000 lux. a : 10 days, b : 20 days.

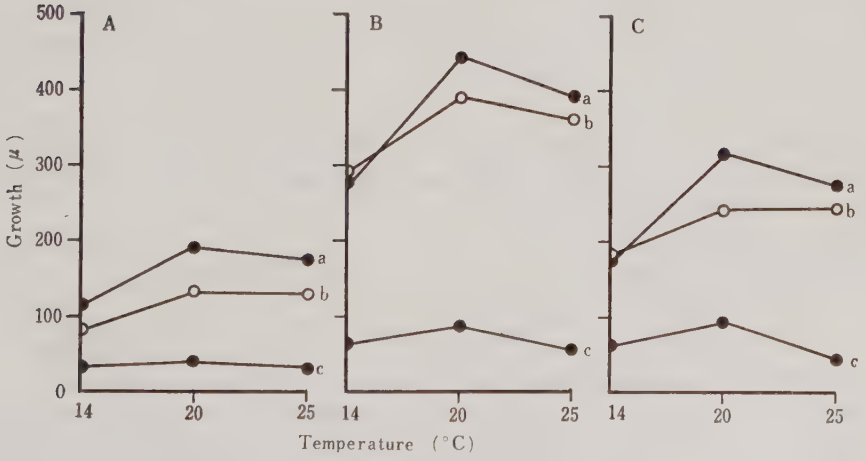


Fig. 31. Effect of temperature on the growth of filaments for both horizontal (A・B) and vertical (C) directions under different intensities of illumination. a : 1,000 lux, b : 500 lux, c : 100 lux.

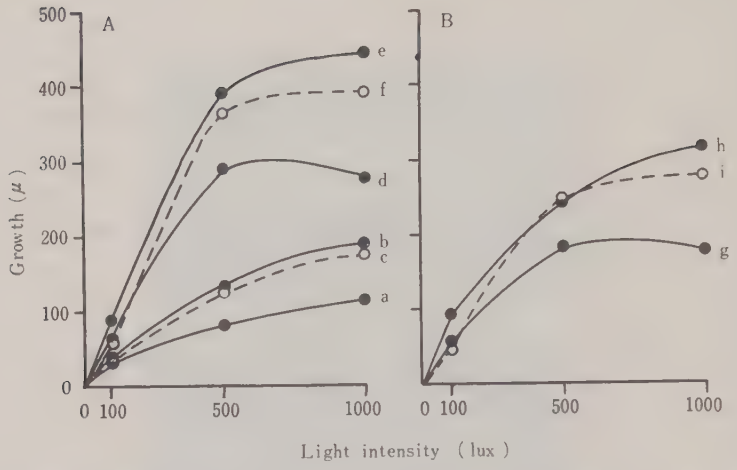


Fig. 32. Combined effect of temperature and light intensity on the growth for both horizontal (A) and vertical (B) directions. a (14°C), b (20°C), c (25°C) : 10 days, d (14°C), e (20°C), f (25°C) : 20 days, g (14°C), h (20°C), i (25°C) : 10 days cultured.

らべてかなり悪くなるにしても致命的ではないようである。もちろん，2および1/8倍というような高塩分および低塩分では生長はほとんど停止する。同じ1/2倍濃度の海水中の生長を，水平方向のばあいと垂直方向のばあいとをくらべると，前者の方が生長がおとっているようにみえるが，これは水平方向の枝は表面に近いため稀釈の影響をうけやすいためとも考えられる。このような傾向はこれまでに水平方向の生長に対してえられた実験結果[30)36)47)63)]とほとんどかわりがない。

室温による培養では，糸状体の垂直方向の生長も水平方向の生長もともにほぼ 2,000 lux あるいはそれよりやや高照度で最高に達するものとみられる。アサクサノリ葉体は 6,000 lux で生長が最高に達するという報告[23)]があるから，糸状体はこれにくらべてかなり低い光量で充分なことがわかる。この結果は，糸状体が直射日光に弱いという結果をうらがきしている。右田（1959）は光の影響に関してくわしく検討をおこない，水温が 15°C のとき 4,000 lux で，20°C のとき 2,000 lux で生長がよいとのべている。これを上記の結果とくらべてみると，えられた数字と傾向においてやや差がみられる。しかしこの差は根本的なものでなく，ノリの種類差，基物である貝殻の差などが原因しているものと思われる。

生長の適温は，光の照度にかかわらず 20°C 附近であると考えられるが，あまり光の量が少ない（100 lux）とほとんど温度の影響はあらわれない。

## 要　　結

1. 条件がほぼ一定ならば，糸状体の垂直的生長は培養日数にだいたい比例して直線的である。
2. 垂直的生長は，高塩分および低塩分いずれのばあいもおさえられる。すなわち，1/2倍濃度の海水中では生長がかなりおさえられ，2倍，1/8倍濃度ではほとんど生長しない。水平方向の生長でもほぼ同じ傾向をみせる。
3. 垂直的生長は，室温培養のばあい 2,000 lux およびそれよりやや高い照度で最高に達するものと思われ，5 lux 以下では生長しない。この傾向は水平方向のばあいもかわりがない。
4. 生長に対して好適な培養温度は 20°C 附近である。25°C では照度によっては生長がやや 20°C よりわるくなるばあいがある。

## 第2節　色光の影響

葉体よりやや深いところに生育し，貝殻などの基物に穿孔するという特殊な生態をしめす糸状体に対して，色光がその生長にどのような影響をおよぼすものか生態学的にしらべる必要があると思われる。糸状体の色素については，すでに第2章でのべたとおり，葉体とかわらない組成をもつが，その吸光特性はややことなっていることをのべた。このようなことと関連して，糸状体の生長におよぼす色光の影響を実験した。

### 材料および方法

アコヤ貝殻を基物としたアサクサノリ糸状体に諸種のフィルターで濾光した光を照射し，20°C で培養した。そのさい光は貝殻面に直角になるように照射された。

フィルターとしては，いろいろな色素を15%ゼラチンにとかしたものを，ガラス板にうすく均一にぬってかわかしたものをもちいた。もちいた各色素およびその吸光極大は下のようである。

ナフトール・イエロー（390, 430 mμ），エリスロシン（515 mμ），アニリン・レッド（550 mμ），ゲンチアン・バイオレット（590 mμ），メチル・グリーン（640 mμ），メチレン・ブルー（670 mμ）。

この吸光極大は，それらの水溶液について分光光電光度計で実測したものである。また同時に透過率曲線をもとめ第33図にしめした。この図からわかるように，各フィルターによって濾光された光はかならずしも

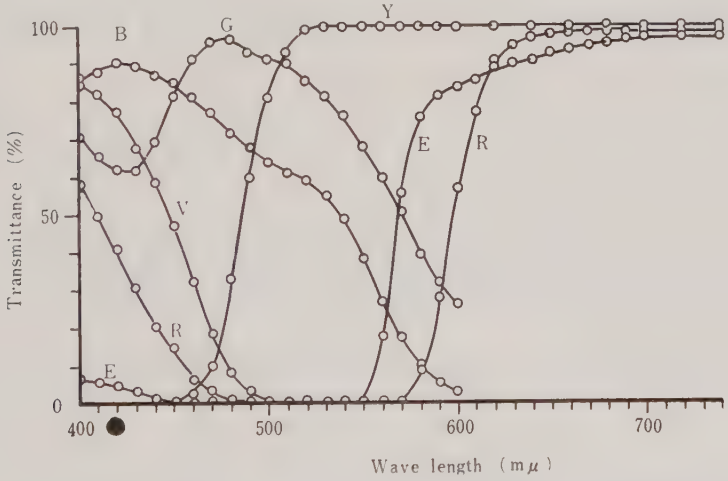


Fig. 33. Spectral transmission curves of some dye solutions employed for color filters. V : Gentian violet, B : Methylene blue, G : Methyl green, Y : Naphthol yellow, E : Erythrosin, R : Aniline red.

単一光に近いものでなく，かなりの幅の波長の光をふくんでおり，とくに赤色フィルターによる濾光はある波長から長波長の光線を全部透過する。

したがってこれらのフィルターをもちいたばあいには単一光線の影響とはいいがたいが，大体の傾向をうかがうことができよう。

色フィルターの光透過率はそれぞれことなっているので，フィルターを透過した色光の照度を一定にするために各貝殻面の照度が 300 lux になるように光源からのきょりを加減した。そしてフィルター以外の部分を黒紙でおおって他の光が入らないようにした。

## 結　　果

1959年12月8日に播種して，12月10日から実験を開始し，10日後と20日後にサンプリングをおこなった。

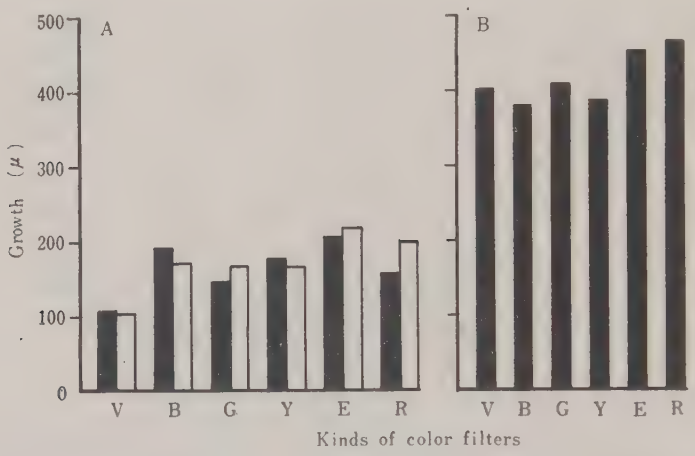


Fig. 34. Effect of the filtrated light by color filters on the growth of *Conchocelis* at 20°C. The intensities of filtrated light on the surface of *Conchocelis*-inhabited shells are all adjusted to 300 lux. A : 10 days, B : 20 days cultured. Solid bars : vertical growth, open bars : horizontal growth. Dyes employed for filters are as the case of Fig. 33.

10日間培養の結果は第34図Aにみられるように，垂直方向の生長（黒ヒストグラム）も水平方向の生長（白ヒストグラム）も，菫色光（ゲンチアン・バイオレット）が照射されたばあいにもっとも悪く，赤色光（エリスロシン）が照射されたばあいにもっともすぐれている。すなわち一般に青色系統の光よりも赤色系統の光がわずかに生長によい影響をあたえるようにみえる。

20日間培養したものでは，垂直生長の状態がふつうの培養のばあいとややことなり，原因はあきらかでないが，貝殻表面に直角に生長するものよりゆるく彎曲しながら斜めの方向に生長するものが多くみられた。したがって，その測定もいままでとことなり，斜めにむかう枝を対象にして測定をおこなったが，その結果は第34図Bにみられるものである。

すなわち，色光の影響の差があまりみられないが，やはり赤色光の下における生長が青色光の下におけるよりややまさっている。

## 考　　察

方法のところでのべたように，この実験にもちいられたフィルターでは，げんみつにせまい波長の色光はえられない。じっさいここにえられた結果には各フィルターによる生長にわずかながらも差がみられるが，この差と光の波長とを直接むすびつけて解析することはむずかしい。しかし 400～550 mμ までの青色光より，550 mμ 以上の赤色光が糸状体の生長に対していくぶんか好影響をあたえることはわかる。

このことは一般に緑色植物でみられる傾向とかわりがないが，ふつう緑色植物においてはこの差がもっと大きい。

色光がアオサの光合成におよぼす影響をみた結果[48]では，赤色光の方が青色光よりかなり効率がよいが紅藻類ではあまり差がないことをみている。すなわち，紅藻類では青色光もよく利用しうるという結果をしめしていて，このことはその色素に phycobilin などの補助色素を有しているためといわれ，HAXO and BLINKS（1950）が，各種海藻類の action spectrum を研究することによってたしかめている。

糸状体の生長においてえられた上記の結果も，このような事実と矛盾していない。

## 要　　結

1. アサクサノリ糸状体は青色光の照射下でも赤色光の照射下でもあまりかわりのない生長をしめすが，赤色光照射下における生長がわずかにまさっている。
2. このことは，アサクサノリ糸状体が phycobilin などの色素を有しているために，青色光でも赤色光でもあまりかわらない光合成をしうることを意味している。
3. したがって，アサクサノリ糸状体は青色光でも生長にさしつかえがないものと考えられる。

## 第3節　水素イオン濃度の影響

アサクサノリ糸状体の生長に対して，海水の pH 値の影響がみられるならばどのていどのものか，これをたしかめるために pH 値をかえた海水中で培養をおこなった。海水の pH 値は NaOH および HCl で調整したが，アルカリ側の調整ははなはだむつかしく，pH 9.5 以上ではただちに白沈を生じた。

また，酸性あるいはアルカリ性のどちらに調整したものも，長期間放置しておくと，密栓をしても pH 値が移動してもとの pH 値に近ずく傾向がみられた。したがって，海水の pH 値を実験の最初における値と，最後の値とであらわし，第7表にしめした。

Table 7. Initial and final pH values of sea water employed for cultivation. Initial pH values are previously adjusted with HCl or NaOH.

| Initial pH | Final pH |
|---|---|
| 5.6 | 7.4 |
| 6.3 | 7.7 |
| 8.2 | 8.2 |
| 9.2 | 8.6 |
| 10.6 | 8.6 |

培養は 1,000 lux の光を照射し 20°C でおこない，10 日後の垂直方向の生長および水平方向の生長を測定した。

1959年12月26日に播種して12月28日に実験を開始した。

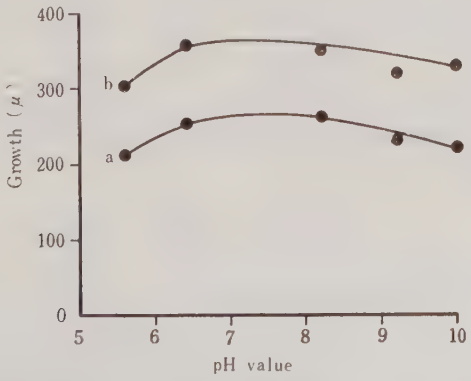


Fig. 35. Influence of pH values on the growth for vertical ( a ) and horizontal ( b ) directions during the 10 days cultivation at 20°C under the illumination of 1,000 lux.

結果は第35図にしめしたように，垂直方向の生長（第35図a）および水平方向の生長（第35図b）は，初期 pH 6.3 のばあいにややよいようにみえるが，一般に初期 pH 値は糸状体の生長にあまり大きい影響をおよぼさないとみてよいであろう。ただ pH 5.6 のばあいは，播種された果胞子のうち発芽しないで膨潤したままでいるものがかなりみられた。また pH 10 のばあいには白色の沈澱が生じてやや異常な点がみられたが，それも大したものでなかった。

右田（1959）は，糸状体の水平方向の生長に対する pH 値の影響を，毎日 pH 値を調整して実験した結果，pH 8.2より pH 7.3 で生長がよく，pH 9 以上で生長が阻害されることをみているから，天然海水より中性に近い pH値のばあいにむしろ生長がよいという傾向は，たしかなようである。

## 要　　結

1．糸状体は，はじめに HCl または NaOH で pH 5.6～10.6 に調整された海水中ではほとんど同様に生長し，pH値による影響をうけないが，しいていえば天然海水より中性に近く調整された海水中でややよ良好な生長をしめすようである。

## 第4節　生長物質の影響

高等植物における生長ホルモン類の作用については，すでに数えきれないほどの研究があり，それらが植物の生長に対して効果のあることはよく知られている事実である。これに対して下等隠花植物，とくに藻類に対する植物ホルモン類の作用については，いままでのところあまり確実な結果がえられていない。

多細胞の海藻類に対する効果については，長谷川（1949）がスサビノリの生長に対するヘテロオーキシンの効果について，木下・寺本（1958）は，アサクサノリに対するジベレリンの効果について研究し，いずれもホルモン類がアマノリ類の生長に効果があるという結果を報告している。

しかしながら海藻類に対するホルモン類の効果についての研究例が少なく，またその効果についてはっきりとたしかめられた段階にいたっていない。

アサクサノリ糸状体については，まだホルモン類の効果がしらべられていないので，この研究ではβインドール酢酸（IAA）とジベレリンが糸状体の生長におよぼす影響をしらべた。

### 材料および方法

いままでと同様の材料をもちいて，1959年2月22日に播種して2月23日から実験をはじめた。

IAA は10, 1, 0.1, 0.01 mg/l, ジベレリンは 1, 0.1, 0.01, 0.001 mg/l の各濃度になるようにそれぞれ自浄海水にくわえ，それらの海水中で糸状体を培養し，15日後と33日後にサンプリングをおこない観察した。

これら海水のしめす pH値は，すべて対照（自浄海水）とほとんどかわりがなかった。

培養温度は20°C，照射光は 500lux であった。

測定は水平方向の生長のばあい枝のさくそうのため測定困難であったので，すべて垂直的方向の生長のみについて第1節と同様の方法でおこなった。

### 結　　果

IAA の影響は15日間の培養結果ではほとんどみとめられない（第36図A－a）が，33日後では，1 mg/l の濃度のばあいにやや生長促進効果がみられる（第36図A－b）。

しかし，真に生長促進に効果があるかどうかこの実験から断定することはできない。

ジベレリンの影響は，15日間の培養結果（第36図B－a）でも，33日間の培養結果（第36図B－b）でもまったくみとめられない。

ただジベレリンの 1，0.1 mg/l 海水溶液中で培養されたものは，表面から肉眼でみた糸状体斑の色が，他

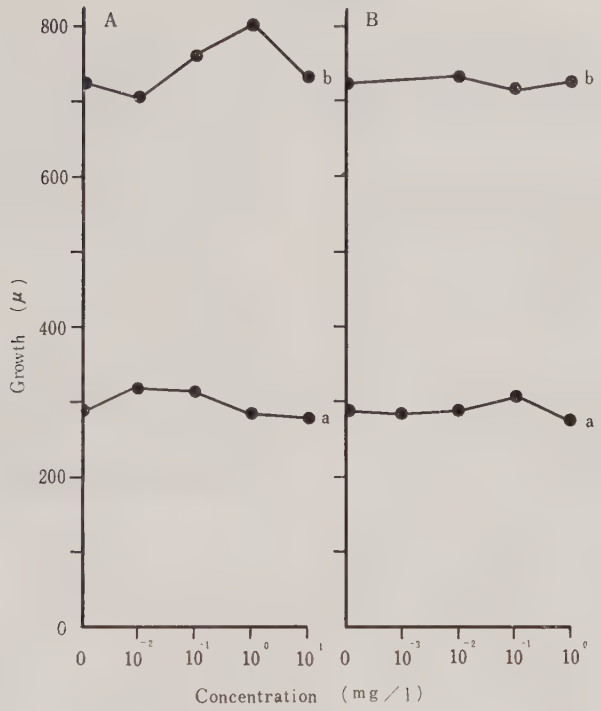


Fig. 36. Influence of growth substances added to sea water on the vertical growth of filaments at 20°C under the illumination of 500 lux. A : IAA, B : gibberellin. a : 15 days, b : 33 days.

のものより濃い傾向がみられた。

IAA のばあいは，対照よりも一般に色があせる傾向があるようである。

## 考　　察

アマノリ類の葉体においては，前述のようにその生長に IAA およびジベレリンは効果をしめすという報告[17)24)]もあるが，糸状体に対してはあまり効果がないといえよう。ただジベレリンはある濃度では糸状体の色を濃くする傾向がみられるので伸長以外になんらかの影響を糸状体にあたえることはたしかである。

## 要　　結

1. アサクサノリ糸状体の垂直的生長に対して，IAA およびジベレリンは，ほとんど影響をあたえない。
2. ジベレリンは，ある濃度では多少糸状体の色を濃くする傾向がある。

## 第5節　栄　養　塩　類　の　影　響

糸状体が，葉体と同じく葉緑素およびその他の補助色素により光合成をおこなって生長する以上，やはり炭酸源がその生長に大きい意味をもっていることはいうまでもない。

また，その他の硝酸塩や燐酸塩も当然糸状体の生育上に必要であろうと考えられる。

このような無機塩類がアサクサノリ糸状体の生長におよぼす影響を，主としてその垂直的生長を対象にしてしらべた。

## 材料および方法

供試塩類は重炭酸ソーダ（$NaHCO_3$），重炭酸カリ（$KHCO_3$），第1燐酸ソーダー（$NaH_2PO_4 \cdot 2H_2O$），硝酸ソーダ（$NaNO_3$），塩化アンモン（$NH_4Cl$），および尿素（$(NH_2)_2CO$）である。これらの塩類を自浄海水に溶解して3段階の濃度のものをつくり，培養液とした。すなわち重炭酸塩については，0.1，0.01，0.001％，他の塩類については，それぞれ0.1，0.01，0.001モルである。これら各塩類の海水溶液がしめすpH値は，燐酸塩とアンモニア塩のばあいをのぞくと，自浄海水のpH 8.2とほとんどかわりがなかった。第1燐酸ソーダのばあいは$10^{-1}$モル—pH 5.0，$10^{-2}$モル—pH 6.0，$10^{-3}$モル—pH 7.0であり，塩化アンモンのばあいは$10^{-1}$モル—pH 7.4，$10^{-2}$モル—pH 7.8，$10^{-3}$モル—pH 8.2であった。

測定の方法はまえとかわらない。

## 結　　果

**重炭酸塩**：$KHCO_3$については，1959年2月21日に播種し，23日に500 lux，20°Cで培養を開始して，15日後と33日後に，$NaHCO_3$については，2月24日に播種したものについて室温，500 luxで26日から培養し，15日後と30日後に測定した。

$KHCO_3$は，15日後の結果（第37図A—a）をみても，33日目の結果（第37図A—b）をみても，糸状体

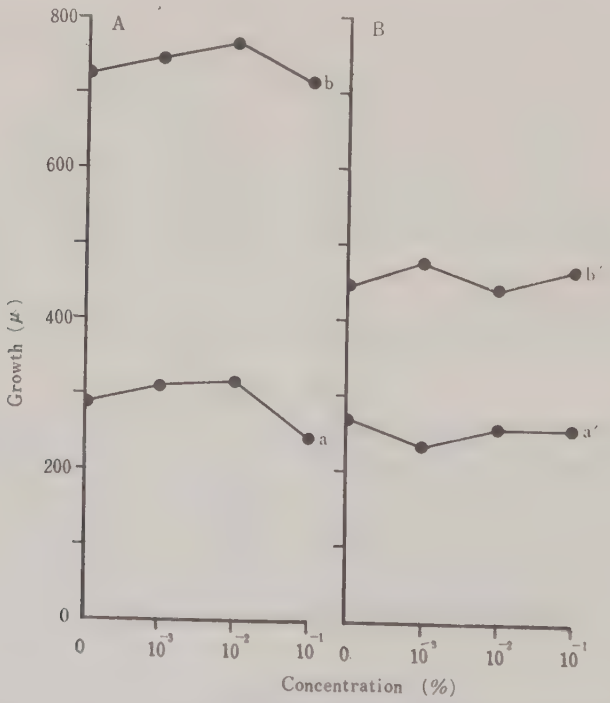


Fig. 37. Effect of bicarbonates added to sea water on the vertical growth of filaments under the illumination of 500 lux.
A : potassium bicarbonate, B : sodium bicarbonate. A : 20°C, B : room temp.
a : 15 days, b : 33 days, a′ : 15 days, b′ : 30 days.

の垂直的生長にほとんど影響をおよぼさないようである。わしろ高濃度では生長がやや抑えられているようにみえる。

$NaHCO_3$ についても同じことがいえる（第37図B—a′, b′）。

ただ興味があるのは，どちらの塩類でも高濃度のばあいには，発芽した糸状体がふつうに貝殻に穿孔するもの以外に，穿孔しないものが多くみられ，それらがガラス上に生長したばあいと同様に貝殻の表面で裸出したまま生育することである。このように裸出した糸状体は，その色も濃くなって培養期間中元気に生長していた。すなわち，重炭酸塩が多いと，糸状体は貝殻に接触していてもあたかも穿孔する必要がないような現象をしめす。

**他の塩類**：1959年3月9日播種，13日から 500 lux，室温で培養を開始し，10日後，20日後，30日後，40日後の4回垂直的生長の測定（20個体平均）をおこなった結果（第8表）では，どのばあいも対照とあまり

Table 8. Vertical growth ($\mu$) of *Conchocelis* affected by some nutritive salts added to sea water (500 lux, room temp.). 0 indicates the death and no growth of germlings.

| Culture duration (days) | 10 | | | 20 | | | 30 | | | 40 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Concentration (mol) / Salts | $10^{-1}$ | $10^{-2}$ | $10^{-3}$ | $10^{-1}$ | $10^{-2}$ | $10^{-3}$ | $10^{-1}$ | $10^{-2}$ | $10^{-3}$ | $10^{-1}$ | $10^{-2}$ | $10^{-3}$ |
| $NaNO_3$ | 154 | 173 | 196 | 314 | 374 | 283 | 484 | 508 | 488 | 718 | 799 | 699 |
| $(NH_2)_2CO$ | 162 | 159 | 177 | 244 | 365 | 277 | 442 | 514 | 477 | 685 | 705 | 743 |
| $NH_4Cl$ | 0 | 0 | 139 | 0 | 0 | 335 | 0 | 0 | 442 | 0 | 0 | 594 |
| $NaH_2PO_4 \cdot 2H_2O$ | 0 | 0 | 165 | 0 | 0 | 282 | 0 | 0 | 493 | 0 | 0 | 618 |
| Control | 132 | | | 414 | | | 513 | | | 743 | | |

かわらないかむしろ下まわった値をえた。わずかに $10^{-2}$ モル $NaNO_3$ でややよい結果のばあいがみられるが，生長促進の度合としては問題にならないていどである。

$NaH_2PO_4 \cdot 2H_2O$ および $NH_4Cl$ のばあいは濃度が高いと有害で枯死してしまい，$10^{-3}$ モルの濃度でも生長がわるい。

1959年12月8日に播種，10日から培養を開始し，4日目，8日目，11日目に水平的生長を測定（10個体平均）した結果（第9表），$10^{-3}$ モル $NaNO_3$ で生長がよいほかは，垂直的生長のばあいとほとんど傾向におい

Table 9. Horizontal growth ($\mu$) of *Conchocelis* affected by some nutritive salts added to sea water (500 lux, room temp.). 0 indicates the death and no growth of germlings.

| Culture duration (days) | 4 | | | 8 | | | 11 | | |
|---|---|---|---|---|---|---|---|---|---|
| Concentration (mol) / Salts | $10^{-1}$ | $10^{-2}$ | $10^{-3}$ | $10^{-1}$ | $10^{-2}$ | $10^{-3}$ | $10^{-1}$ | $10^{-2}$ | $10^{-3}$ |
| $NaNO_3$ | 75 | 125 | 126 | 267 | 281 | 429 | 438 | 484 | 508 |
| $(NH_2)_2CO$ | 34 | 83 | 124 | 0 | 243 | 243 | 0 | 445 | 497 |
| $NH_4Cl$ | 0 | 0 | 133 | 0 | 0 | 305 | 0 | 69 | 451 |
| $NaH_2PO_4 \cdot 2H_2O$ | 0 | 67 | 85 | 0 | 165 | 211 | 0 | 253 | 314 |
| Control | 162 | | | 348 | | | 478 | | |

てかわりがない。

また表面観察によって糸状体の分枝の状態をしらべても，とくにこれらの塩類が分枝を促進している様子もみられなかった。ただ $NaNO_3$ は一般に糸状体の色をよくするから，色素の形成や健康にとっては影響があるものとおもわれる。

## 考　　察

光合成に必要と思われる炭酸源として，重炭酸塩を海水にくわえても，とくに糸状体の生長を促進するようにはみられない。また重炭酸塩があたえられたばあいは，元来穿孔すべき発芽体が穿孔しないで貝殻上をはって生長する傾向さえみられる。このことは重炭酸塩が多いと貝殻中に穿孔する必要がないことを意味しているようである。逆にいえば穿孔するということは炭酸源を貝殻中にもとめることであると解釈される。貝殻は炭酸カルシウムであるから，これを溶解することによって容易に炭酸がえられるから，このような仮定もむりではないと思われる。ガラス上で発芽した裸出糸状体は，重炭酸塩をあたえられると生長がよいこともこのことと関係があると思われる。

海水にくわえられた他の栄養塩類が，糸状体の生長に対してあたえる影響は窒素化合物では硝酸ソーダがよく，尿素はあまりかわらず，塩化アンモンはかなりわるい影響をおよぼすようである。このようなことは右田（1959）が水平方向の生長についてえた結果とかわりがない。燐酸塩もわるい影響をあたえる。

このように塩類の添加によってとくに生長がよくなることはないが，糸状体の健康その他の生理的意味がまったくないとはいえない。黄斑病にかかったものに対して $NaNO_3$ は一時的にしろ回復させることがある。黒木（1953a）は糸状体の培養において，$KNO_3$ 0.1 g/l，$Na_2HPO_4$ 0.02 g/l をくわえた海水をもちいている。TSENG and CHANG（1955a）は，1ミリモル $KNO_3$ と0.1ミリモルの $KH_2PO_4$ を入れた海水を培養にもちいている。これらの例における各塩類の濃度は，硝酸塩ではほぼ$10^{-3}$モル，燐酸塩では$10^{-4}$モルに相当しているからこの実験においてもちいた最低$10^{-3}$モルは，燐酸塩としてはやや高濃度であったかもしれない。

## 要　　結

1. 海水に重炭酸塩をくわえても，とくに糸状体の生長を促進することはない。
2. 重炭酸塩が多いと，発芽した糸状体の多くが穿孔しないで，そのまま貝殻面上をはって生長する傾向がある。
3. 海水に燐酸塩や窒素化合物をくわえても，とくに糸状体の生長が促進されるような傾向はみられない。

## 第6節　流動パラフィン中の生長（糸状体の生長と炭酸源）

前節でのべたように，貝殻中における糸状体の生長が海水にくわえられた重炭酸塩によってとくに促進される傾向はみられない。このことは糸状体がその葉体と同様の光合成色素により，光合成をおこなって生長すると考えられるにもかかわらず，海水中の炭酸源がその光合成にとってあまり対象にならないことを意味しているものと思われる。すなわち光，温度さえふつうの培養とかわりがなければ，培養液は海水でなくてもよい可能性が考えられる。

このことをたしかめるために，糸状体が生育している貝殻を流動パラフィン中に沈めて，外部からのいっさいの炭酸源から遮断された状態において培養し，ふつうに海水中で培養したばあいと，その生長を比較した。

### 方法および結果

1960年1月9日に播種をおこなって，実験開始までのあいだ5日間約300 lux照射下で放置し，糸状体が多少穿孔した貝殻を，約1 cm の厚さの流動パラフィンをみたしたシャーレの底に沈めて培養した。

培養は室温で 500 lux 照射のもとに，1月14日からはじめた。11日間培養の結果を第38図にしめした。

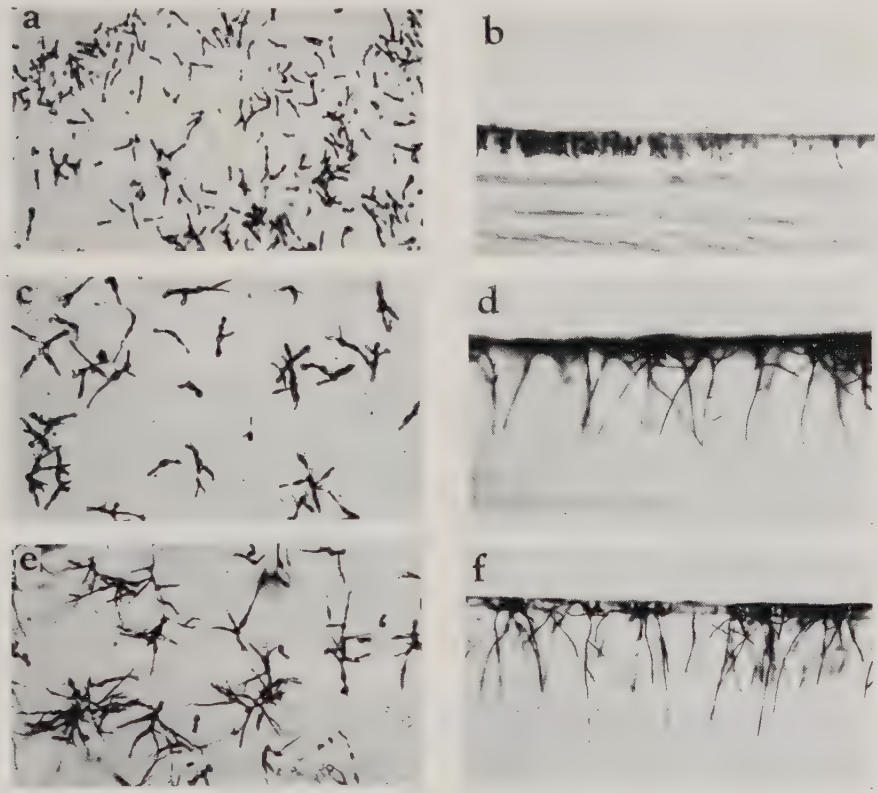


Fig. 38. Growth of shell-inhabiting *Conchocelis* cultured in liquid paraffin for 11 days (500 lux, room temp.).
a・b : Initial stage before experiments.
c・d : Natural growth of shell-inhabiting *Conchocelis* cultured in sea water.
e・f : Somewhat slender but almost similar growth pattern of shell-inhabiting *Conchocelis* cultured in liquid paraffin.
a・c・e : surface views, b・d・f : profile views in respective cases. ×100.

海水中（第38図c・d）でも流動パラフィン中（第38図e・f）でも貝殻中に穿孔した糸状体はほとんどかわりがない生長をしめす。すなわち実験をはじめたときは約 40 μ の垂直的生長（第38図a・b）であったのが，11日の培養でどちらも約 200 μ まで垂直的に生長をしたわけである。また貝殻上にのこっている母胞子も，流動パラフィン中のものの方がむしろ海水中のものより色がよく元気なようにみえる。ただ流動パラフィン中のばあいは糸状体がやや細い傾向がある。

その後培養をつづけて22日間経過したものでは，どちらも約400 μ の垂直的生長をしめしており，やはりそのあいだに大差がみられない。ただ流動パラフィン中で22日間培養をした貝殻の表面観察では，途中で枯死したようにみえる糸状体が多少存在することがわかった。また流動パラフィン中の培養が長期におよぶと，貝殻表面に，ごく小さい気泡が無数に生じているのが観察された。流動パラフィンは攪拌されないで静置された状態でも，空気中の酸素をあるていど拡散通過させるといわれているが，空気中における分圧の少ない炭酸ガスでは，このようなことはほとんどおこりえないと思われる。したがって酸素はともかく，少なくと

も炭酸ガスに関するかぎり，空気中から流動パラフィン層をへだてて，貝殻面に達することはないといえるから，この実験では糸状体に対する外界からの炭酸ガスの供給はまったくないと考えてよい。しかし，この点をさらにげんみつにするために，60°C で約1時間加熱して含まれていたガスが除かれたと思われる流動パラフィンを急速に冷却し，容器の中に厚さ約8cmになるようにみたしたものを用意し，そのなかでふたたび貝殻中の糸状体を培養した。

材料は2月9日に播種した後，室内のやや暗い場所で2月15日まで放置して，アコヤ貝殻中に少し穿孔生長したものをもちい，上記の流動パラフィン中に浸し，容器自体を密封して培養（室温，1,000 lux）をおこなった。

2月15日からふつうに海水中で培養したものを対照にして実験をはじめて，3月1日にサンプリングした結果，やはり垂直方向にはどちらも約300 μの生長をしめしており，3月28日には750〜800 μに達していた。実験を開始したときの垂直的生長は約40 μであった。表面観察では流動パラフィン中のものは，生長がわるく形態が不規則で，中には途中で枯死したようにみえるものもかなりあった。その状態は第39図にみら

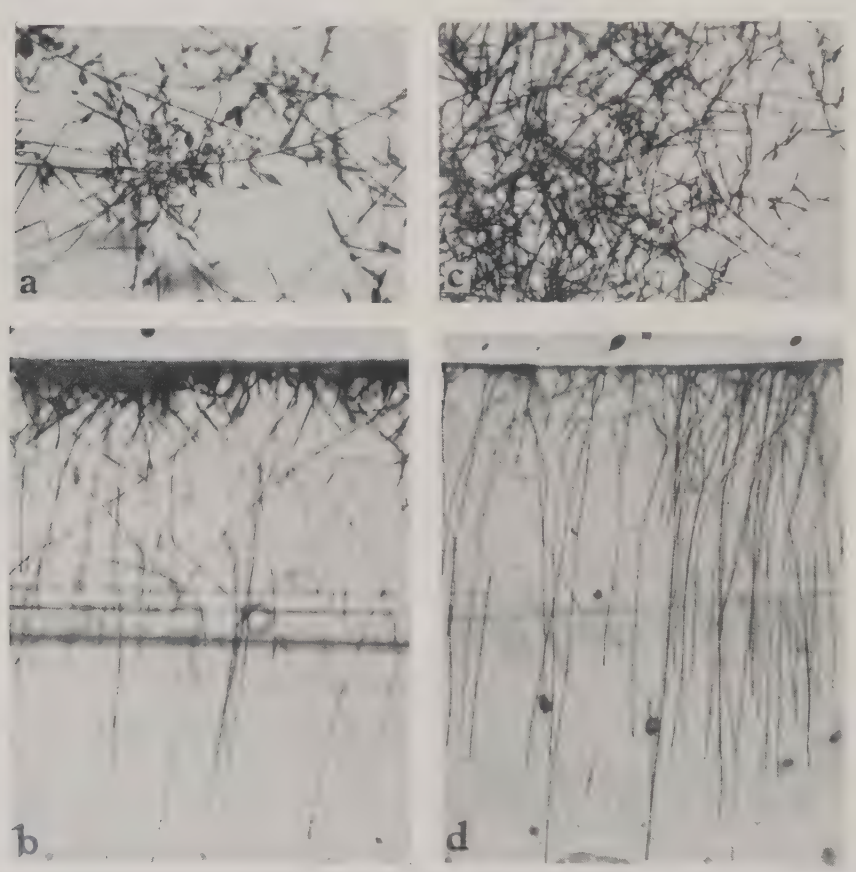


Fig. 39. Growth of shell-inhabiting *Conchocelis* cultured in liquid paraffin for prolonged period (42 days) in another experiment (1,000 lux, room temp.). a・b : Control, c・d : Rather few branching in shell-inhabiting *Conchocelis* cultured in liquid paraffin. a・c : surface views, b・d : profiles. ×100.

れるとおりである。この図からみてわかるように，流動パラフィン中で培養したものは，垂直方向の形態も

ふつうとことなって細く，かつ分枝が少なくて貝殻の内層へ比較的まっすぐに伸長するようである。流動パラフィン中で培養中，貝殻の表面に小さい気泡が一面に生じたことも前と同じであって，この気泡が流動パラフィン中を上の方へにげさる様子はみられなかった。

この貝殻表面に生じる気泡はごく小さいものであるから，ガス交換の対象としては問題にならないものと思われる。

## 考　　察

以上の事実から考えて，糸状体の生長に対しては，かなりの長期間にわたって海水はかならずしも必要でなく，光，温度が適当なら外界から遮断された状態でも糸状体はあるていど生長しうるものと考えられる。

この事実を，すでにえられた実験結果，すなわち糸状体は炭酸カルシウム性物質以外のものには穿孔せず，しかも炭酸カルシウム性のものならばその起源や性質をとわず，ほとんどすべてのものに穿孔生長しうる事実，ガラス上で発芽した糸状体は生長がわるく枯死しやすいが，貝殻中で生育しているものは生長がよく夏の高温にもたえうること，しかしガラス上の裸出糸状体でも，海水中に重炭酸塩をくわえることによって，色も生長もよくなること，貝殻中の糸状体の生長には外部からの炭酸源の供給はあまり必要がないらしく，むしろ培養液中に重炭酸塩が多いときは，糸状体は貝殻に接触しても穿孔せず，面上を裸出したまま生長する傾向が強いことなどの事実とあわせて考察すると，アサクサノリ糸状体は貝殻中の炭酸カルシウムの分解産物を，あるていど光合成の炭酸源にして生長しうる能力があるものといえよう。

## 要　　結

1. 貝殻中に穿孔しているアサクサノリ糸状体は，光と温度がてきとうならば流動パラフィン中にひたされた状態でも，相当期間海水中で培養されたばあいとほとんどかわりのない生長をしめす。
2. このことはアサクサノリ糸状体が外部とのガス交換をたたれても，かなり長期間生存しかつ生長しうることをしめす。
3. したがってアサクサノリ糸状体は，炭酸源を基物である貝殻の炭酸カルシウムにもとめていると考えられる。

# 結　　論

## A　ノリ糸状体の形態について

1．糸状体が貝殻中に穿孔するばあい，糸状体は貝殻の表面に沿った方向はもちろん，内層の方向にも垂直にあるいは彎曲して生長し，ついには反対側の面に達する。
2．貝殻内層の糸状体の生長は，貝殻表面がどちらをむいていても，それに対する糸状体の生長方向には変化がない。すなわち糸状体の生長方向に対しては重力の影響がないとおもわれる。
3．糸状体が種類のことなる貝殻に穿孔したばあい，やや形態がことなることがある。そして貝殻の構造にその生長が規制されることがあり，たとえばタイラギ殻稜柱層中では，その蜂巣状の区画内だけで生長する傾向がつよい。
4．糸状体が貝殻以外の石灰性基物中に穿孔するときは，その形態に差があらわれることがある。たとえば方解石中ではその劈開の方向に影響されることがある。ウシケノリ糸状体のばあい，この傾向がいちじるしい。
5．糸状体がセメント中に穿孔したばあいはセメント中の粒子およびその集団に，団塊状に穿孔しているようにおもわれる。
6．糸状体の培養中に貝殻の表面にカルシウム性の突起ができるが，この中にも糸状体が存在する。
7．各種イワノリ類糸状体の生長の状態も，アサクサノリのばあいと平面的にも垂直的にも大差がみられない。ウシケノリ，フノリノウシゲのばあいも，とくにめだった差はみられないが，やや膨大部が大きい傾向がある。
8．単胞子嚢枝は初夏から秋にかけて生ずるが，イワノリ類の単胞子嚢枝は季節的にアサクサノリよりはやく生じ，形態もやや細くかつ長く内層にむかって生ずる傾向がある。
9．これら単胞子嚢枝は貝殻表面に少なくともその一端が達している。
10．単胞子嚢枝は表層にかなり近い内層に存在する枝の一部から発生して，しだいに内層方向に生長肥大し，ある時期に表面に達して，そこに開口をもつようになる。
11．この単胞子嚢枝が表面に達して生じる開口は，単胞子嚢枝の太さとほぼ同じていどの直径をもつ。
12．果胞子が発芽して最初に貝殻に穿孔した穿入孔は，約5μていどの直径をもつ小孔である。

## B　ノリ糸状体の穿孔性および代謝について

1．糸状体は，炭酸カルシウム系の物質ならば，生物起原のものにかぎらず鉱物性のものにも穿孔生長しうる。そして鉱物性炭酸カルシウムは，その結晶系のちがいなどには関係なく基物となりうる。
2．糸状体細胞の pH値は5～6であり，しかも炭酸カルシウムは pH5～6で容易に溶解するから，糸状体は炭酸カルシウムを溶解して穿孔生長するものとおもわれる。
3．果胞子が，ガラス上で発芽して裸出糸状体となったばあい，その生長にはカルシウム塩より重炭酸塩の方が効果があるから，糸状体が炭酸カルシウム系基物中で穿孔して生長するのは炭酸カルシウムの構成要素である炭酸にあるということが考えられる。
4．貝殻中で生育している糸状体は，わずかであるが，呼吸と光合成にもとづくガス代謝をしめす。このとき補償点は5～50 lux とみられ，葉体にくらべて相当低い値である。このことは5 lux 以下では垂直的生長をしめさない事実とよく一致する。
5．糸状体は葉体とおなじく光合成をおこない，その色素もかわりがないが，ただ糸状体自体がしめす吸光特性は葉体とややことなっている。

## C ノリ糸状体の生長と環境要因について

1．糸状体の垂直的生長と培養期間との関係は，条件が一定ならば直線的傾向をしめす。
2．塩分濃度が極端に高いばあいまた低いばあいは，生長がおさえられる。
3．糸状体の生長は 2,000 lux かあるいはそれよりやや高い照度の下で最高に達するが，生長適温以外ではこの照度が最高の効果をしめすとはかぎらない。
4．糸状体の生長の適温は，20°C附近である。
5．赤色光は青色光よりやや糸状体の生長に有利なようであるが，あきらかではない。
6．糸状体は pH 5.6 ないし 10.6 の範囲の海水中で培養されたばあいには，生長のていどにあまり大きな差がみられない。しかし天然海水よりわずかに中性に近い pH 値のばあいに生長がやや良好のようにみえる。
7．β−インドール酢酸およびジベレリンは，糸状体の生長に直接の影響をあたえない。
8．海水に燐酸塩，硝酸塩などの栄養塩類を添加しても，直接糸状体の生長を促進することはないが，糸状体の健康などには関係するらしい。
9．海水に重炭酸塩を添加しても，糸状体の生長を直接促進することはないが，重炭酸塩が海水中に豊富であると，糸状体が穿孔しないで裸出したまま貝殻表面をはって，元気に生長する傾向がある。
10．貝殻に穿孔している糸状体は，流動パラフィン中でも温度，光が適当なら海水中のばあいとほとんどかわりのない生長をしめす。すなわち，糸状体は外部とのガス交換を断たれた状態で貝殻内で生長したことになる。したがって糸状体は光合成の炭酸源を貝殻に求めて生長するものとおもわれる。

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# Studies on the growth of *Conchocelis*

by

Eizi Ogata

## Summary

Since the discovery of *Conchocelis*-phase in the life-history of *Porphyra umbilicalis* by Drew (1949), the technique for aquiculture of *Porphyra tenera* (Japanese laver) has developed rapidly depending on her theory of *Conchocelis*. But the fundamental knowledges concerning the growth of *Conchocelis* are not yet far advanced. It seems, therefore, to be important to know the fundamental theories on the growth of *Conchocelis* in order to establish the technique for aquiculture of Japanese laver.

In this investigation, the fundamental experiments on the growth of *Conchocelis*-phase of some species of *Porphyra* and *Bangia* were carried out concerning both morphological and physiological aspects, since 1955 at Osaka and also at Yoshimi, Shimonoseki in Japan.

## Growth patterns in *Conchocelis*-phase with especial reference to the vertical growth

The observations on the growth patterns of *Conchocelis* in shell have been made by the surface view. Scarcely any has been known about its growth behavior in the vertical direction. In this connection successful observations were made mainly on the *Conchocelis* of *Porphyra tenera*, appropriately using pearl oyster shells. The following new procedure for preparation enabled us to follow the growth in a whole profile view.

Several rectangular pieces were cut out of pearl oyster shells which harbored the filaments: these pieces were cemented together and sticked onto a microscopic slide with a sort of synthetic resin. The surfaces of section were carefully ground extremely thin with a grindstone. Profile of the filament growth in thus prepared specimens becomes easily accessible in transmitted light.

1. Most germlings spread tap-root-like filaments downwards into the shell. These main filaments subsequently produce lateral branches which later run upwards and finally reach the shell surface. Thus grown up branch filaments form an anastomosed layer just underneath the shell surface. After the subsequent culture, the main tap-root-like branches extend to reach the opposite surface and thereafter soon produce lateral branches again thriving into anastomosed filaments in the inside layer close to the opposite surface.
2. Direction of the growth of tap-root-like filaments has no correlation with the direction of gravity. That is, tap-root-like filaments always elongate perpendicu-

larly to the shell surface irrespective of the normally supine, inverted and upright positions of the shell.

3. The *Conchocelis* filaments show different forms depending on the sort of shell from different shell-fish even when the spores come out of the identical mother plant. For example, *Conchocelis* grows restricted within the honeycomb-like compartments of prismatic layer of *Atrina pectinata japonica* shells as if arrested by the separating walls.
4. Growth patterns of *Conchocelis* in some sorts of calcareous matrices differ a little from that in marine shell. For example, the branches of *Conchocelis* of *Porphyra* growing in calcite tend to elongate along the cleavage planes of the crystal. These characteristic angular branches are more frequently observed in the *Conchocelis* of *Bangia*. Moreover, *Conchocelis* is able to thrive in the cement mortar probably penetrating some particles of cement powder.
5. The "goose skin-like" projections produced on the surface of *Conchocelis*-inhabited shell permits the penetration of filaments as well as the original shell.
6. The *Conchocelis*-phase observed in several species of *Porphyra* has no remarkable difference among their growth patterns in both horizontal and vertical directions, including the case of *Bangia fusco-purpurea* and *B. gloiopeltidicola*.
7. Fertile cell-rows formed in shell-inhabited *Conchocelis* cultured till autumn have such diverse forms as arch-like or long projected shapes.
8. The fertile cell-rows in species other than *Porphyra tenera* are slender and long as compared with those of *Porphyra tenera*.
9. Fertile cell-rows have several terminals reaching the shell surface indicating the presence of opening for spore liberation.
10. The openings of fertile cell-rows at the shell surface have almost the same size as the fertile cell-rows in diameter.
11. Initial fertile cell-rows originate from the *Conchocelis*-filaments present at shallow layer underneath the shell surface, soon reaching the shell surface to have the opening.
12. Another type of opening bored by the germlings from a spore of *Porphyra tenera* has rather small diameter measuring about 5 $\mu$.

## Perforating growth of *Conchocelis* in the inorganic calcareous matrices

The *Conchocelis*-filaments of *Porphyra tenera* are able to perforate in such inorganic calcareous matrices as calcite, aragonite and limestone growing up into the *Conchocelis*-phase identical with the ordinary ones in marine shells.

The mechanism of the perforating growth of *Conchocelis* in calcareous matrix is elucidated to some extent from the following results obtained.

1. Hydrogen ion concentration in the cell contents of *Conchocelis* is estimated to be pH 5 to 6.
2. Calcareous substance is easily corroded by such weak acid as pH 5 to 6.

3. It seems, therefore, to be probable that the growing branches of *Conchocelis* penetrate the calcareous matrix and inhabit in it.
4. Growth of *Conchocelis*-filaments germinated and grown freely on glass slide without calcareous matrix is favored more by addition of bicarbonate to sea water than by added calcium salt.

## Metabolism in the *Conchocelis*

Inhabiting in marine shells, *Conchocelis* develops into anastomosed filaments under proper condition. Therefore the metabolic activities in the growing process of *Conchocelis* are the interesting problem to investigate.

1. It is found that the shell-inhabiting *Conchocelis* shows the obvious gas exchange by examining the dissolved oxygen content in sea water employed for culture and also the change of gas pressure in manometric measurement under both dark and illuminated conditions.
2. These gas exchanges seem to result from photosynthetic or respiratory processes in *Conchocelis*.
3. Conpensation point in the *Conchocelis* is found to be as low as 5 to 50 lux, which is far lower than in adult *Porphyra* thallus.
4. *Conchocelis* possesses essentially the same photosynthetic and accessory pigments as the adult *Porphyra* thallus. Accordingly, the photosynthetic process in *Conchocelis* is considered to be identical with that in mother *Porphyra* thallus.

## Environmental factors affecting the growth of *Conchocelis*

Growth of *Conchocelis* is undoubtedly affected by various environmental factors. Such effects were studied mainly by examining the vertical growth of *Conchocelis*.

1. Growth of *Conchocelis*-filaments in both horizontal and vertical directions is stopped by highly concentrated or diluted sea water. The growth is reduced to about one half in twice diluted sea water.
2. The growth of filaments tends to reach maximum under the illumination at 2,000 lux.
3. The growth of filaments is not seriously affected by lower or higher hydrogen ion concentration of sea water.
4. *Conchocelis* grows better under the red light illumination than under the blue light.
5. Growth substances such as IAA and gibberellin have no effect on the growth of *Conchocelis*.
6. Enrichment of sea water with nutritive salts such as bicarbonate, phosphate, nitrate or ammonium salt does not significantly improve the growth.
7. The germlings cultured in the sea water rich in bicarbonate tend to grow up into bare creeping filaments on the shell surface showing no shell-inhabiting growth. Accordingly, they seem to need no calcareous matrix to inhabit in the carbon source-rich sea water.

8. Shell-inhabiting *Conchocelis* is able to grow, under adequate conditions of temperature and illumination, even when the surrounding sea water is replaced with liquid paraffin. It is assumed that the *Conchocelis* has an ability to utilize the carbon source derived from the calcareous matrix for photosynthesis.

PLATE

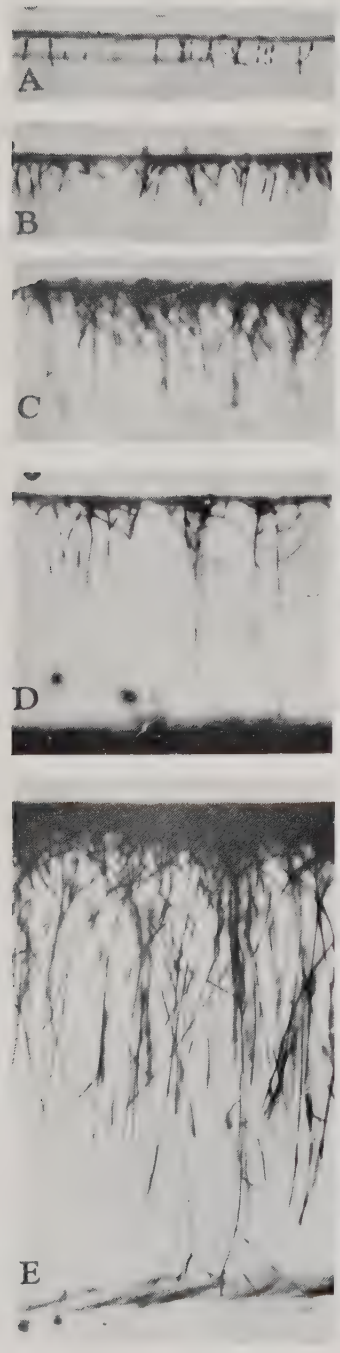
## PLATE I

Profile and surface views of the growing in *Conchocelis*-phase of *Porphyra tenera* KJELLMAN.

A～G : Successive stages of vertical growth in pearl oyster shell, cultivated for 5, 10, 20, 30, 60, 100 and 130 days respectively.

H : Profile of vertical growth of filaments in oyster shell, cultivated for about 1 year.

I～M : Surface views of horizontal growth in pearl oyster shell, cultivated for 5, 20, 30, 60 and 130 days. All × 100.


A
B
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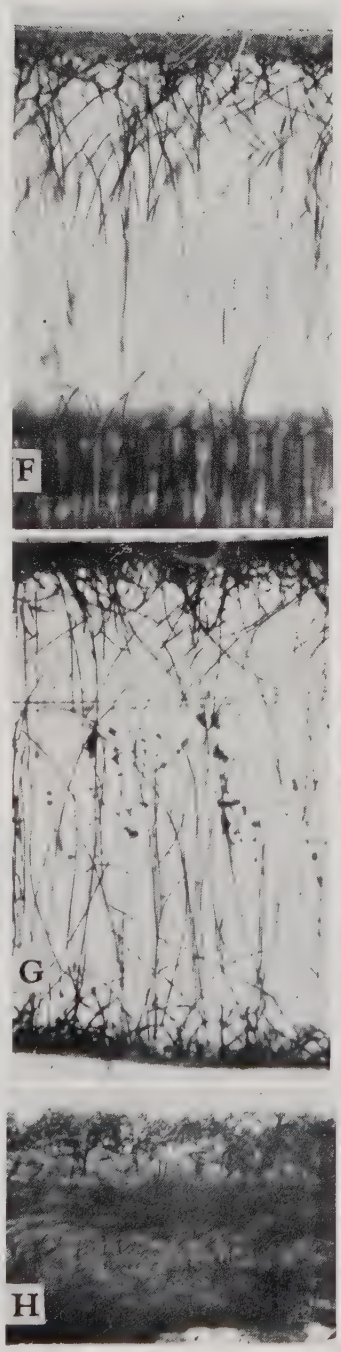
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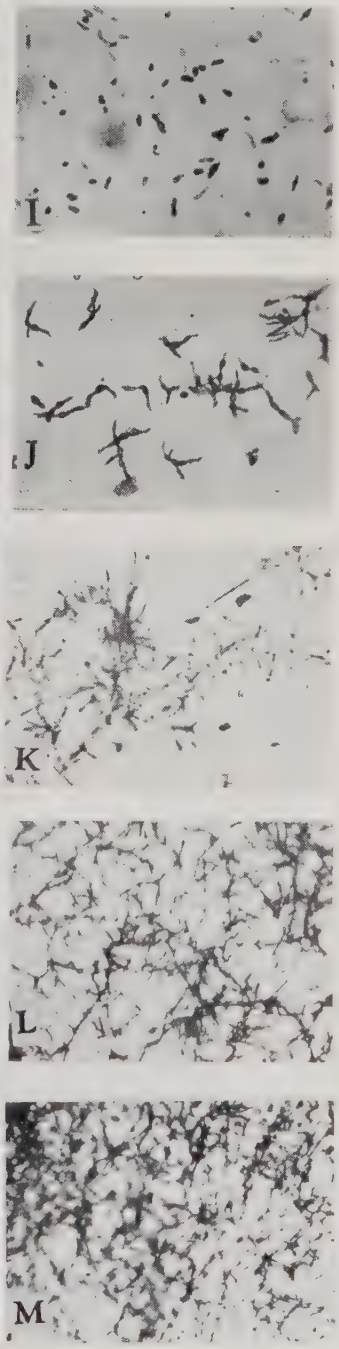

I
J
K
L
M

## PLATE Ⅱ

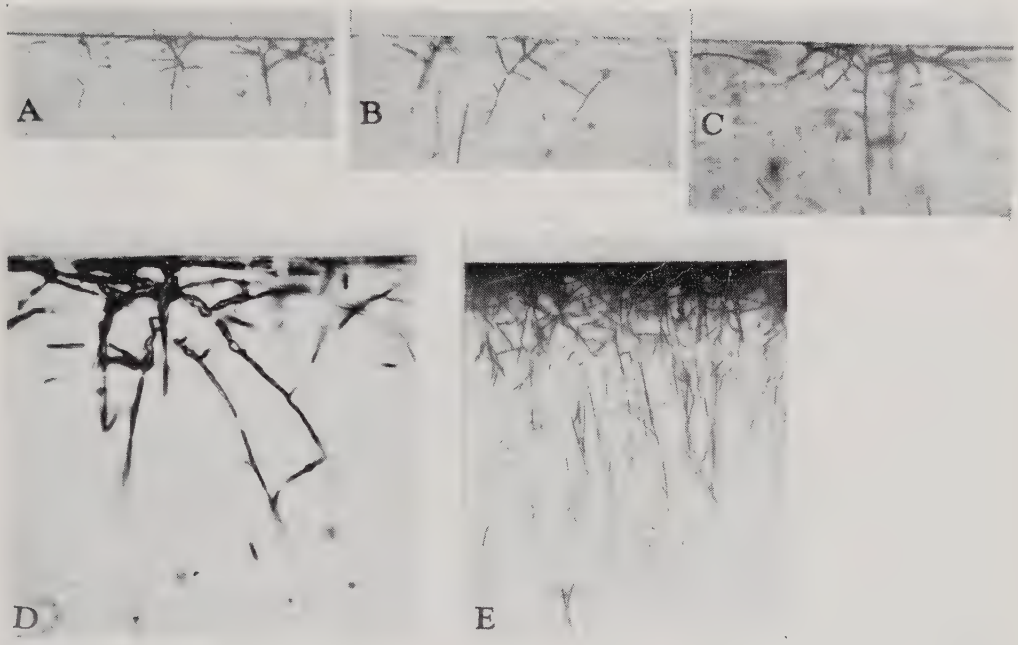
Details of vertical growth and branching in *Conchocelis* of *Porphyra tenera* KJELLMAN in early stages.

A~E : Details of vertical growth and branching, cultivated for 20, 20, 30, 50 and 70 days respectively. All × 100 except D ( × 200 ).

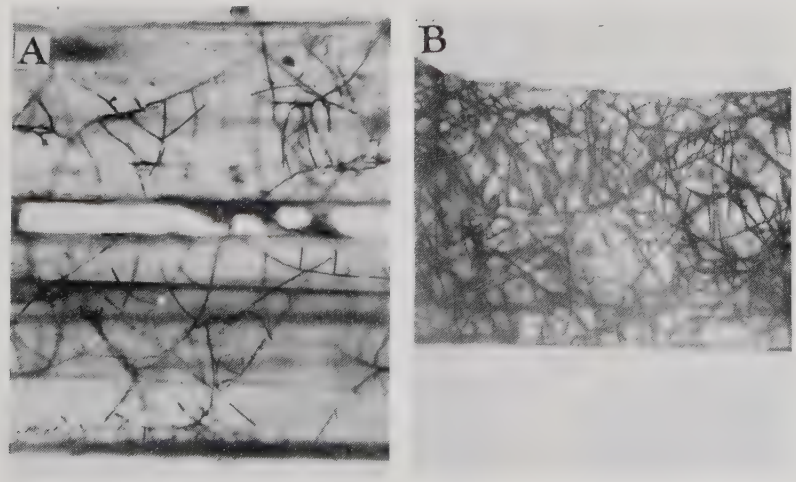
## PLATE Ⅲ

Horizontal growth of *Conchocelis* of *Porphyra tenera* KJELLMAN at the surface of section of shell pieces.

A : 30, B : 50 days cultured. × 100.


A
B
C
D
E




A
B

## PLATE IV

Growth of *Conchocelis*-filaments of *Porphyra tenera* KJELLMAN in the shell under the gravity in different directions (indicated by arrows).

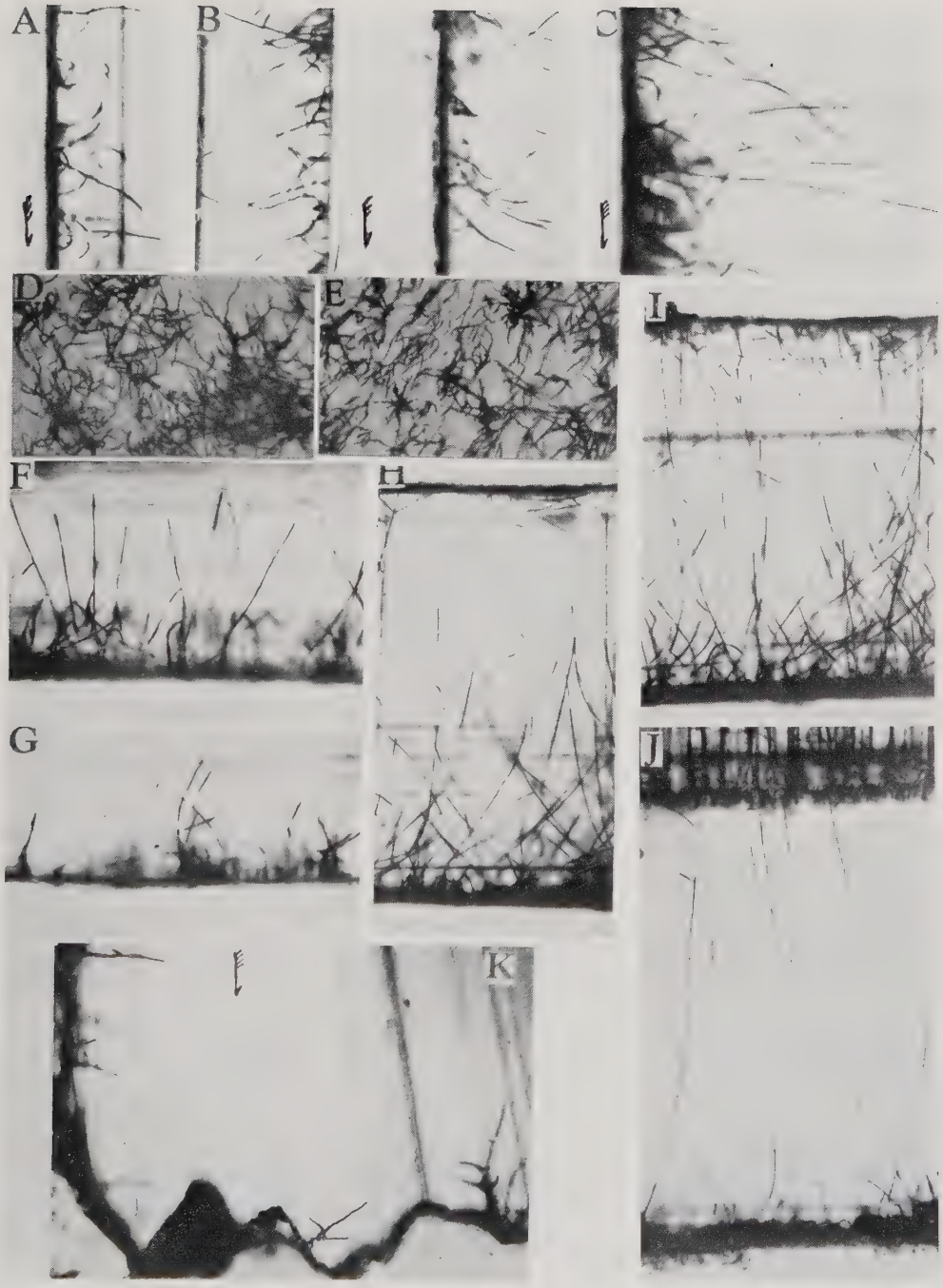
A～C : Profile *Conchocelis* growth in the shell placed upright. A : 15 days, B : 30 days, C : 40 days.

D・E : Surface view of the above case. D : 40 days, E : 110 days.

F～J : Profile of the upwards growth in the shell placed inverted for 30 days (F・G) and for 95 days (H～J).

F・H・I : Cticle and prismatic layers of outer shell surface are previously removed. G・J : Not removed.

K : Profile of the growth at serrated shell surface. Germlings grow vertically to each serrated surfaces. All × 100.


A
B
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## PLATE V

*Conchocelis*-phase of *Porphyra tenera* KJELLMAN growing in the shell matrix of different origin.

A • B : *Conchocelis*-filaments growing in the shell of *Meretrix lusoria* (RÖDING).

C • D : *Conchocelis*-filaments growing in the shell of *Mya japonica* JAY.

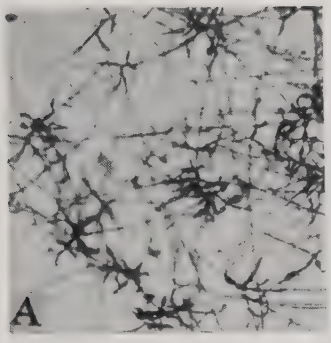
E • F : Shell matrix is shell of *Quadrula metanerua* RAFINESQUE.

G • H : In the shell of *Haliotis gigantea* GMELIN, growth pattern of *Conchocelis* is just the same as in the case of *Pinctada martensii* (DUNKER).

I ~ L : Shell matrix employed is somewhat soft shell of *Atrina pectinata japonica* (REEVE).

I • J : Growth pattern in the pearl layer.

K • L : In the prismatic layer, growth pattern of *Conchocelis*-filaments shows the characteristic growth which is restricted by the structure of prismatic layer. A • C • E • G • I • K : Surface views in the shell of respective species. ×100 except K (×200). B • D • F • H • J • L : Profile views. ×200. A~H : Cultured for 30 days, I~L : for 20 days.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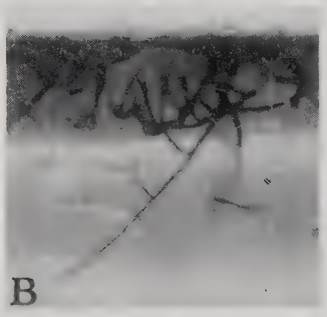
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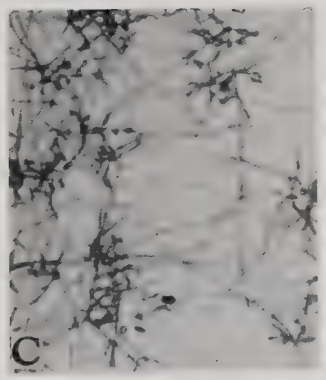
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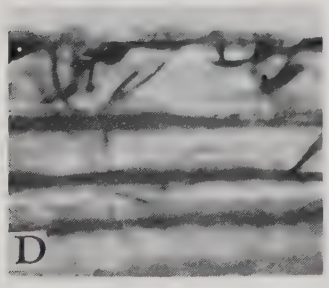
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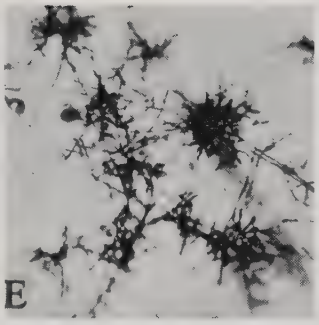
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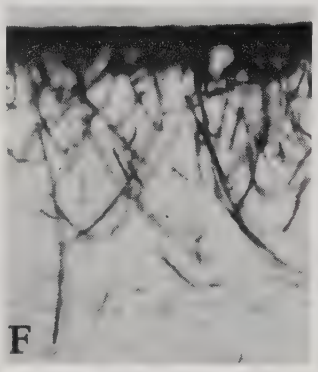
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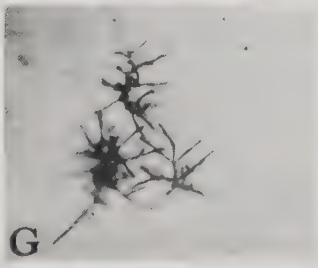
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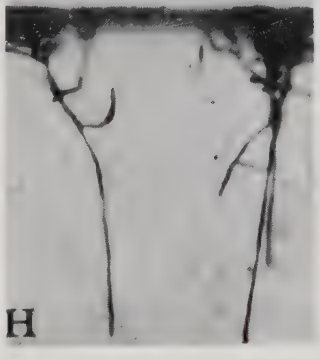
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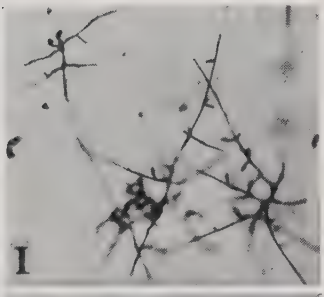
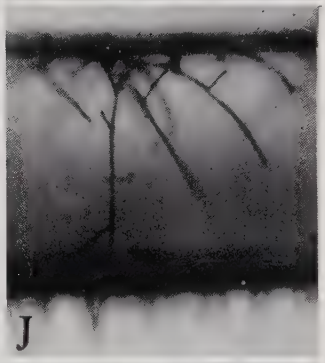

I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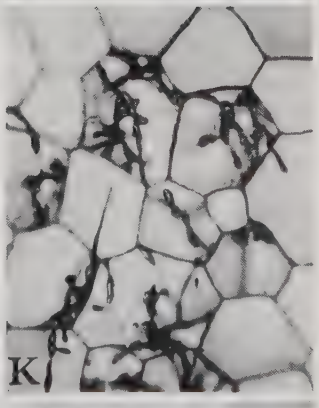
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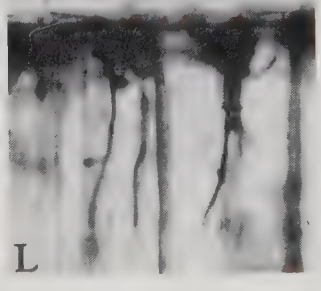

L

## PLATE VI

Profile features of rough touch surface of shell in which the *Conchocelis* of *Porphyra tenera* KJELLMAN inhabit.

A～F : Profile views of projections appearing on the surface of pearl oyster shell. All ×200.

A : Projections produced on shell surface during 100 days cultivation.

B : Projections on prismatic layer (100 days).

C・D : Cocentric layers inside the projection (130 days).

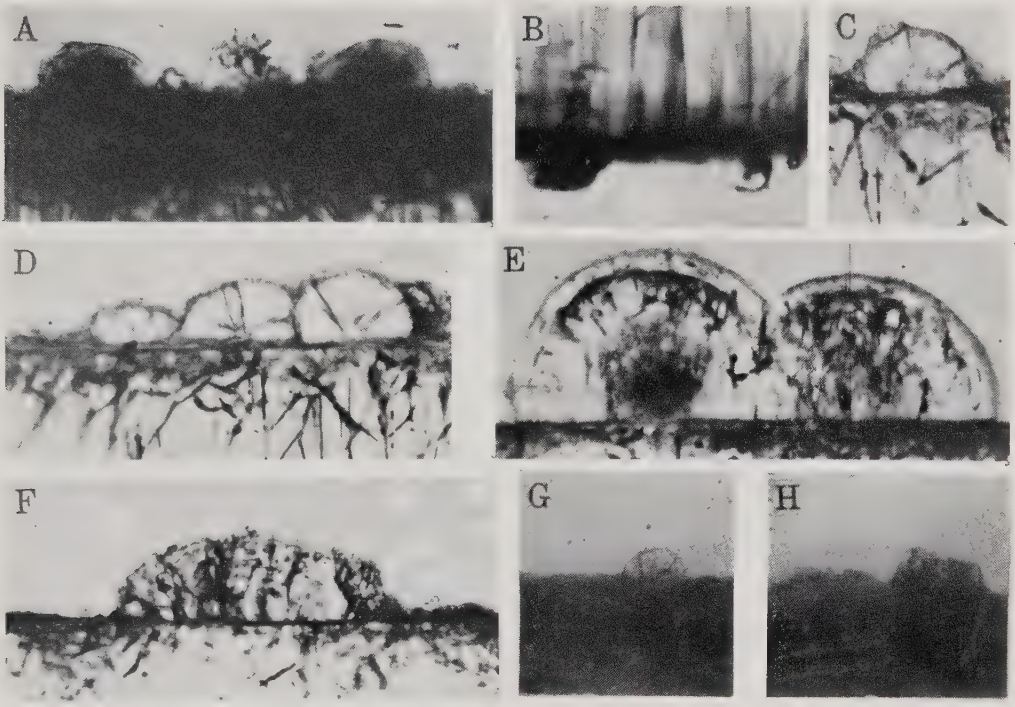
E・F : Giant projections with tubule-like structures inside (150 days).

G・H : Same projections on the surface of oyster shell (*ca* 1 year cultured). ×160.

## PLATE VII

Deposited crystals on the bottom of *Conchocelis*-culturing vessel.

A : Small stage. B : Large stage. ×200.


A
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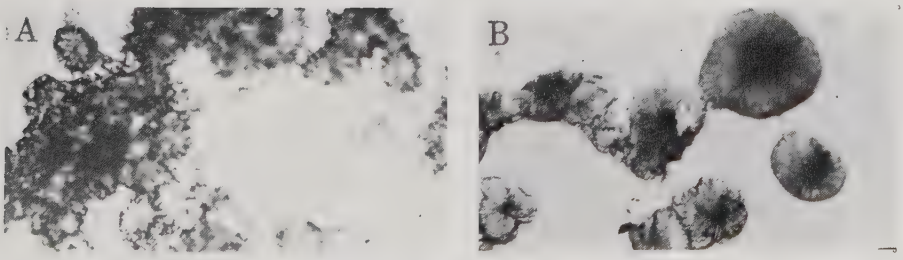
F
G
H




A
B

## PLATE VIII

Surface or profile appearances of shell-inhabiting growth of *Conchocelis*-phase in several species of *Porphyra* and *Bangia*.

A • B : *Conchocelis*-phase of *Porphyra suborbiculata* KJELLMAN cultured for 76 days.

C • D : *Conchocelis*-phase of *Porphyra okamurai* UEDA cultured for 80 days.

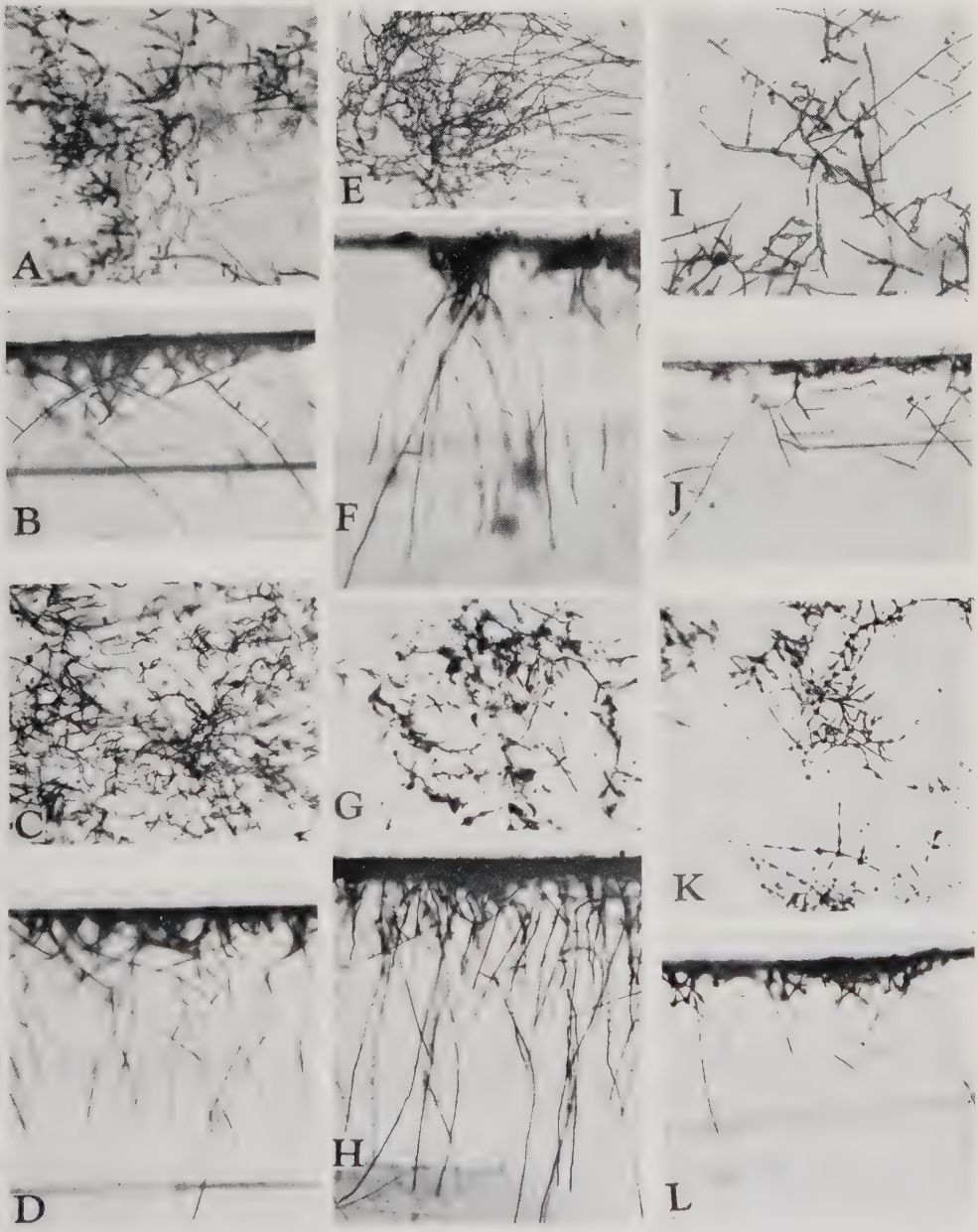
E • F : Somewhat streaming features in the *Conchocelis*-phase of *Porphyra pseudolinearis* UEDA cultured for 70 days.

G • H : *Conchocelis* of *Porphyra dentata* KJELLMAN after 200 days cultivation.

I • J : *Conchocelis* of *Bangia fusco-purpurea* (DILLWYN) LYNGBYE cultured for 60 days ( I ) or 55 days ( J ).

K • L : Somewhat characteristic features in the *Conchocelis* of *Bangia gloiopeltidicola* TANAKA cultured for 85 days.

A • C • E • G • I • K : Surface views. B • D • F • H • J • L : Profile views. × 100.


A
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I
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K
L

## PLATE IX

Profile views of fertile cell-rows formed in the *Conchocelis*-phase of *Porphyra tenera* KJELLMAN.

A • B : Formation of fertile cell-rows in the layer just underneath the shell surface on which spores germed.

C . Formation in the prismatic layer at the opposite surface.

D • E : At the bordering position between the prismatic and pearl layers, they are also formed. A ~ E : about 10 months cultured.

F . When cultured for about 7 months.

G . Inflated branches formed in the "gooes skin-like" projection during 11 months cultivation.

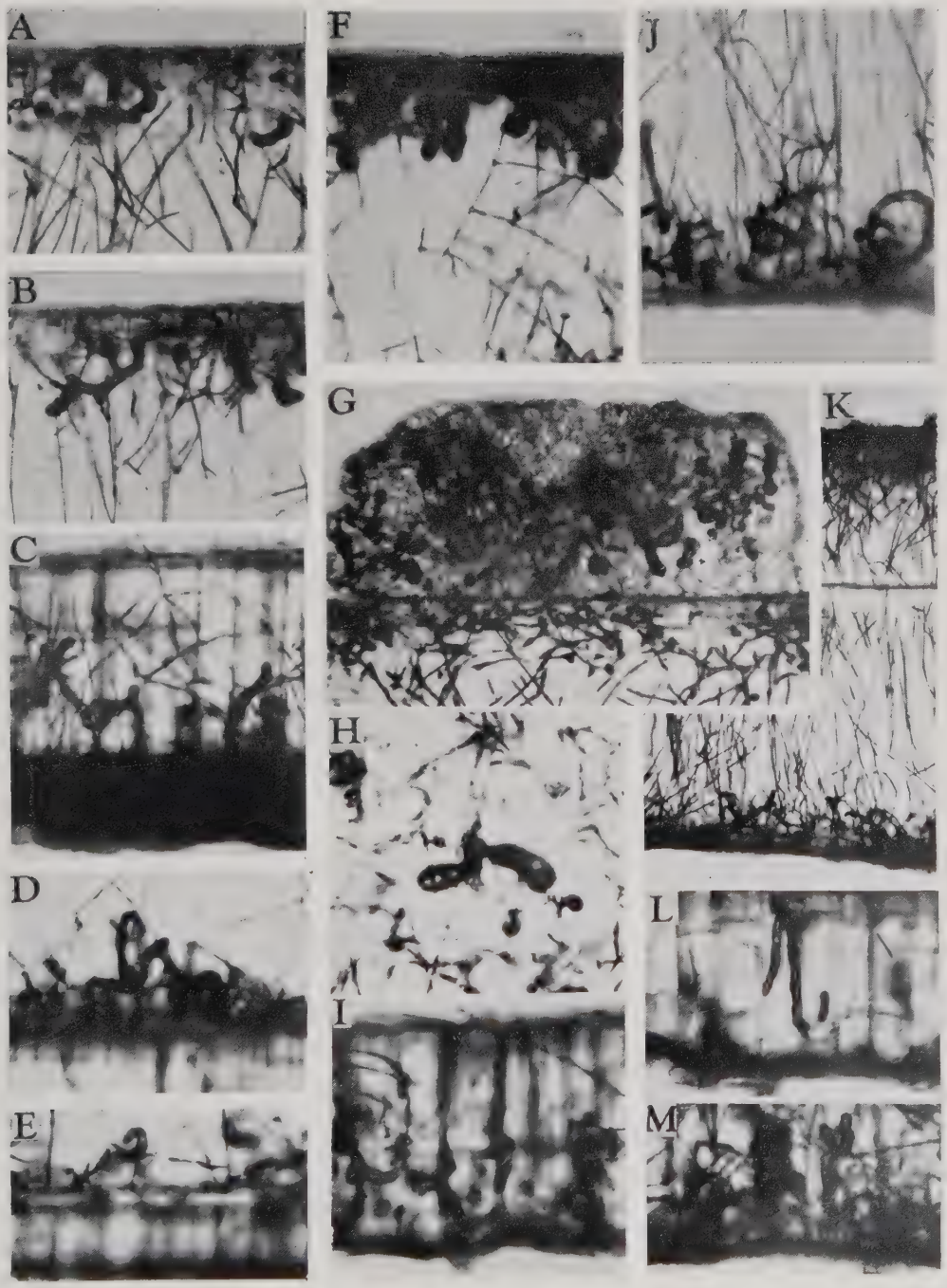
H : Surface feature in the culture of 7.5 months.

I In the prismatic layer of 7.5 months cultivation.

J . Formation in the bottom layer near the outer shell surface.

K . Whole aspect of section. Fertile cell-rows are shown at the bottom area.

L • M : In the prismatic layer. J ~ M : about 1 year cultured. All × 200. except K ( × 100 ).


A
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M

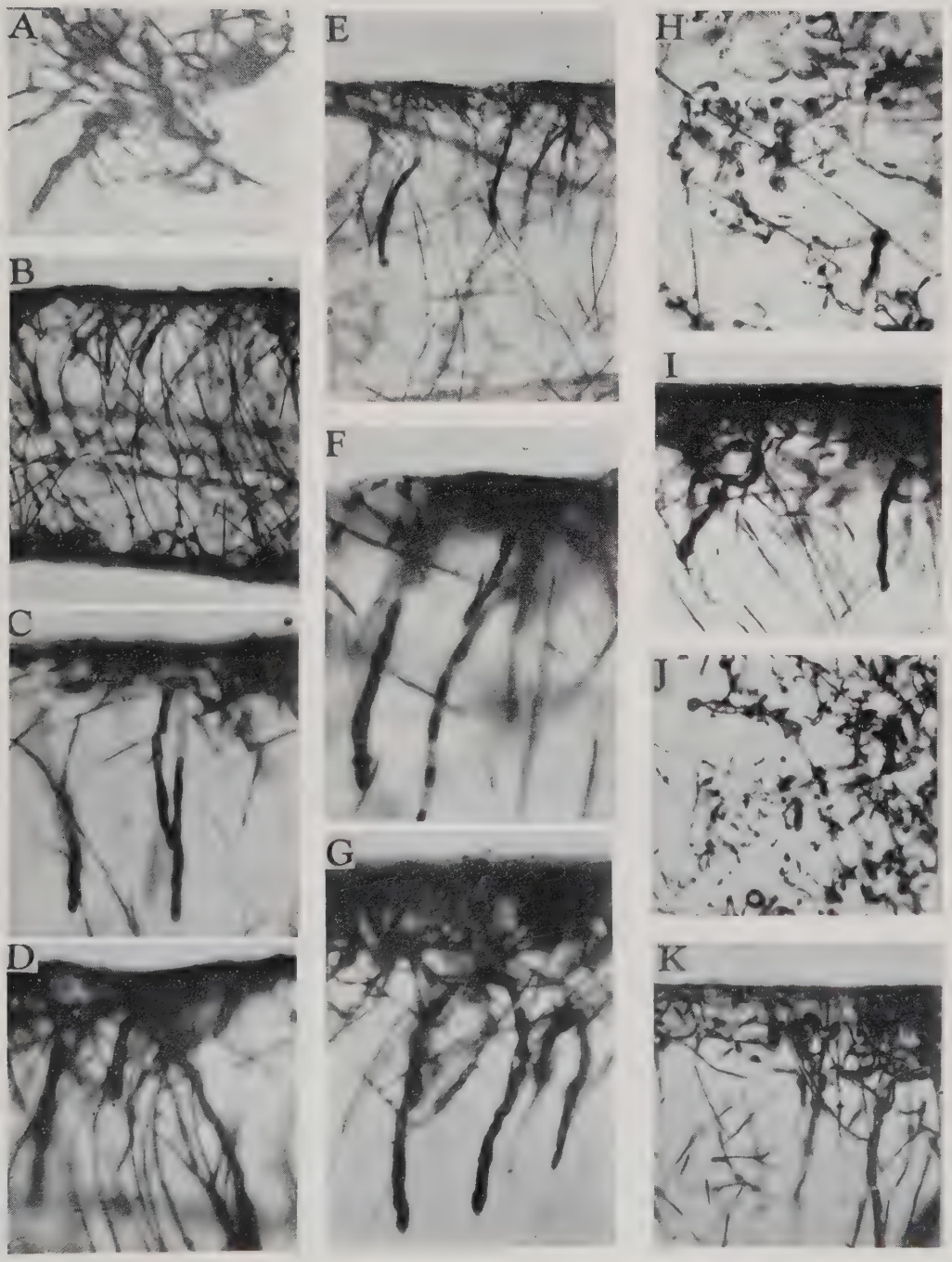
## PLATE X

Fertile cell-rows in the *Conchocelis*-phase of *Porphyra suborbiculata* KJELLMAN.

Formation of fertile cell-rows in the *Conchocelis*-phase of *Porphyra suborbiculata* KJELLMAN is illustrated following the successive stage.

A～D : 200 days, E～G : 234 days, H • I : 266 days, J • K : 308 days cultured.

A • H • J : Surface views, others : profile features. All ×200 except B and E (×100).


A
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D
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F
G
H
I
J
K

## PLATE XI

Fertile cell-rows formed in the *Conchocelis*-phase of some species of *Porphyra* and *Bangia*.

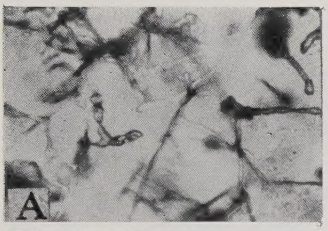
A～E : Straight or arch-like shapes of fertile cell-rows are observed in the *Conchocelis*-phase of *Porphyra okamurai* UEDA.
A～C : 210 days, D : 285 days, E : 307 days cultured.

F～H : In the case of *Porphyra pseudolinearis* UEDA. F・G : 190 days. H : 300 days cultured.

I・J : In the case of *Porphyra dentata* KJELLMAN, 250 days cultured.

K～O : In the case of *Bangia fusco-purpurea* (DILLWYN) LYNGBYE. K～M : Beed-like filament in pearl oyster shell, 265 days. N・O : Fertile cell-rows in the shell of *Atrina pectinata japonica* (REEVE), 220 days cultured.

A・F・I・K・O : Surface views in the case of respective species. Others are profile features. All × 200 except L ( × 100).

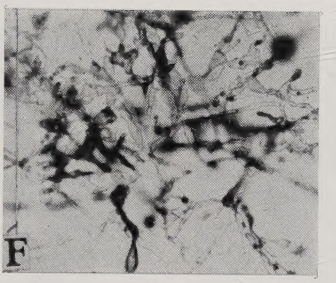

A

B

C

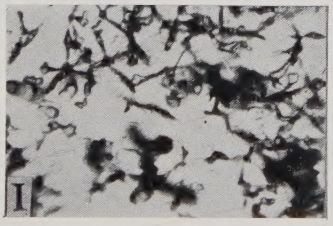
D

E

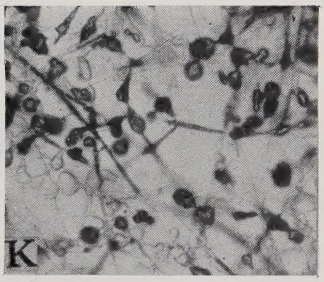

F

G

H


I

J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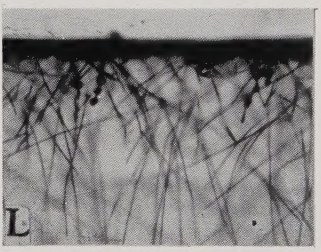
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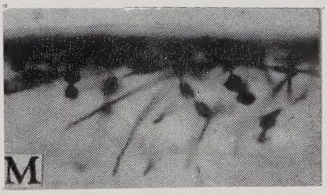
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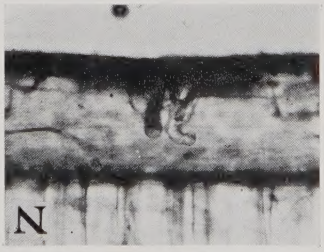
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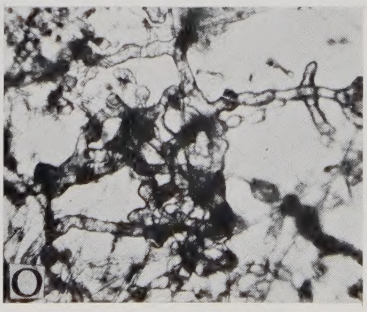

O

## PLATE XII

Formation of outlet opening from fertile cell-row towards the shell surface.

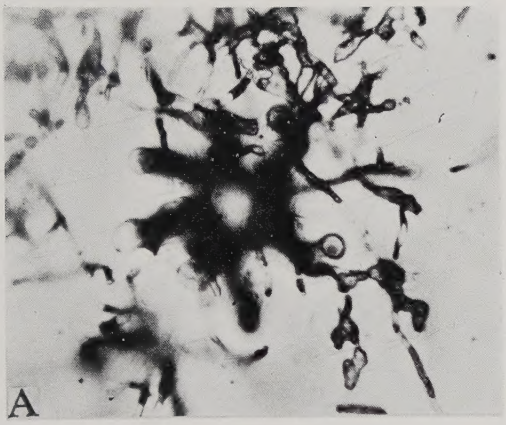
A : Group of outlets for spore liberation from fertile cell-rows of mature (7 months old) *Conchocelis* of *Porphyra okamurai* UEDA.

B : Side view of the outlet opening from fully mature (10 months old) *Conchocelis* of *Porphyra* sp.

C • D : Fertile cell-row developing from 15 weeks old culture of *Conchocelis* of *Porphyra suborbiculata* KJELLMAN. Terminal opening not yet formed.

E : An advanced stage in the development of fertile cell-row into U-shaped profile in 16 weeks old culture as above.

F : *Conchocelis* germling in a beginning stage (7 days old) of boring into shell matrix of *Atrina pectinata japonica* (REEVE). Initial entrance approximately 5 $\mu$ in diameter. All × 400 except F ( × 1,000 ).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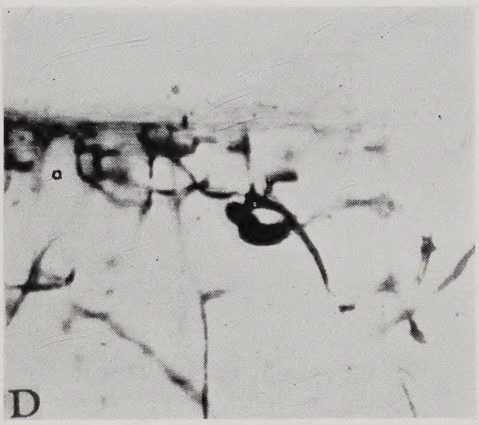
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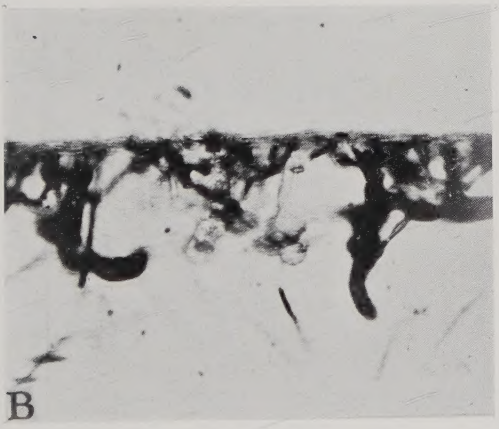
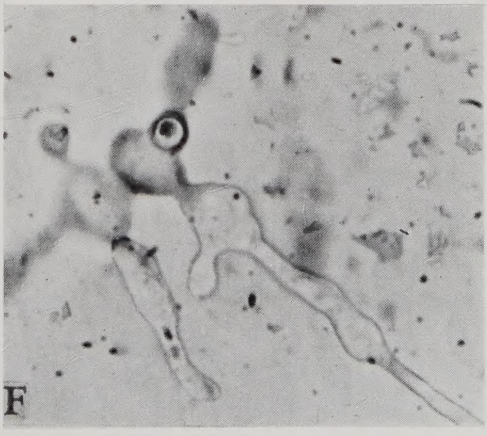

B

E

C


F